How to Prevent ELECTRICAL TROUBLES

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PREFACE

SOME time ago, an electrician friend of mine asked me to recommend a practical book on maintenance work. He wanted, so he said, not a book crammed with theory and formulae, but one based upon actual experience, at a price within the means of everybody.

A short search convinced me that the only way to supply exactly what was wanted was to write it myself, and it is offered to others of the great brigade of practical electricians in the hope that they also will find it acceptable. Even if it only helps to solve just one of the many problems that go to make up a working day, it will have served its purpose.

I should like to acknowledge my indebtedness for some of the facts concerning the drying of flooded machines to the U.S. technical press ; and in particular, to the Westinghouse " Electric Journal."

Also I wish to acknowledge the loan of illustrations :— Fig. 7, courtesy of Messrs. Morgan Crucible Co. Ltd. ; Figs. 9 and 10, courtesy of the Waverley Book Company Ltd. ; Figs. 19, 20, and 24, courtesy of the British Thomson-Houston Co. Ltd. ; Figs. 21, 22, and 23, courtesy of Messrs. Johnson and Phillips Ltd.

In conclusion, if any reader cares to offer, via the publishers, either criticism or suggestions, I shall be most grateful.

E.B.W.

How To Prevent
Electrical Troubles

A practical book on the maintenance of industrial and domestic electrical apparatus, with notes on insulating material and tables of useful operating and repair data

BY

E. B. WATTON, A.M.I.E.E., Assoc.Amer.I.E.E.

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CORDWALLIS WORKS, MAIDENHEAD,

BERKS.

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HOW TO PREVENT ELECTRICAL TROUBLES

CHAPTER I

GENERATORS AND MOTORS (GENERAL)

Cleanliness

THE two chief enemies of electrical machinery are dirt and moisture. Eliminate these, and you immediately cut down your chance of trouble to a fraction of the original hazards. This applies even more forcibly to motors than to generators, since the latter are usually located in engine rooms, where the working conditions are reasonably good, while motors must frequently operate in isolated positions and under the worst possible conditions.

Moisture invariably acts on the insulation, reducing its dielectric strength, and causing a risk of breakdown. Dirt can act in any one of several ways. If it is of a conducting nature, it may form leakage paths from the brushgear or other live conductors to earth ; if gritty, it will get under the brushes and cause bad sparking and commutator wear, and into the bearings causing bearing wear. In any case, it will be sucked into the machine by windage action, and will choke up the ventilating ducts and cause overheating, possibly to the point of insulation failure, and a complete burn-out. Cases have occurred where the accumulation has been sufficient to cause actual jamming of the rotor in the air-gap.

Removal of Dirt. The three main methods of ensuring cleanliness are wiping, blowing, and suction. The first is to be preferred for all accessible portions of the machine, and should be carried out with dusters reasonably free from fluff, and *not* with waste, which is only admissible for the very outside of the carcass. It is not to be recommended even there, as the cotton linters and fluff will be sucked in by the machine, if care is not taken.

Blowing is carried out either by hand bellows, by portable electric blowers, or by a compressed air supply where available. Hand blowers may be effective for very small machines, but electric blowers are to be preferred. If compressed air is used, two things are essential. Firstly, the air supply must be free from moisture, and secondly, the pressure must in no case exceed 50 lb. per sq. in. It should preferably be very much less, 20 lb. being about the best pressure, otherwise there is a danger of damage due to sand-blast effect. Objection has been raised to blowing, on the ground that the dirt is merely blown into the atmosphere, and sucked in again; or, where several machines are located together, the dirt is transferred from one to the others.

Suction is sometimes used, in the form of a small vacuum cleaner, but this method will not, of course, remove stubborn dirt, as effective blowing will do.

An ideal method would be a combination of the two, and in some cases (notably in America) large machines are covered with a kind of portable tent which is connected to a vacuum cleaner before blowing is carried out. Ideals are, however, frequently unattainable, and the plain blower will probably continue to hold the field for a long time.

Blowing should be carried out from once every six months for machines in exceptionally clean surroundings, to as often as once a week for ordinary motors in exceptionally dirty places.

Where motors are specially enclosed and provided with air filters, they will not require this service, but the filters must

be periodically cleaned, or trouble will arise due to lack of ventilation caused by the throttling effect of a choked filter.

MOISTURE. As almost all insulation used in machine windings is more or less hygroscopic, i.e. moisture-absorbing, it follows that efforts should be made to keep moisture away as far as possible, and motors should not be installed in damp places unless it is absolutely unavoidable. In no circumstances must water be allowed to drip on to a motor, and should one be of necessity installed under a leaking roof, a shield should be improvised to divert the drips.

If the machine is installed in a damp atmosphere, it will come to no harm while actually running, as its own warmth will keep it dry. When shut down for long periods, however, some form of heating should be provided to keep it from getting damp, particularly if it runs at a high voltage. A low-temperature heating element or even a 60 watt lamp placed so that warm air rises through the motor, will save a great deal of trouble in the long run. If a motor has been allowed to get damp, and its insulation resistance low, it should be dried out by several hours operation on a reduced voltage, and then a run at full voltage on no-load, before resuming normal duties.

Bearings and other Mechanical Matters

There are two main types of bearing in common use, *plain* or *sleeve*, and ball and roller bearings.

PLAIN BEARINGS. A typical example of a plain or sleeve bearing is shown in fig. 1. The shaft journal rotates in a bronze or brass bush, frequently lined with white metal. The bush or sleeve is usually split into two halves, the upper half or *cap* having oil grooves cut in the internal surface. The oil is fed to the grooves by the oil ring, or rings, which are, as shown, much larger than the shaft, and which revolve slowly by friction, taking up a thin film of oil from the reservoir which is kept filled to the correct level, as shown by an oil gauge.

There are several points to be noted in connection with the correct lubrication of this type of bearing.

1. The correct grade of oil must be used as recommended by the manufacturer. Oil which tends to turn "gummy" may cause sticking of the rings and possibly a seizure. If too thin it will leak out.

2. Spasmodic oiling should be avoided. It is a great temptation to wander round with an oil can at frequent intervals, and put some oil into each machine, with the feeling that one is performing a good deed. Actually, no greater mistake could be made, and the uneasy feeling that "bearings need oiling," must be sternly suppressed. Bearings do—but windings do not, nor do commutators, slip-rings, brushgear, or cables. An over-oiled bearing will leak oil along the shaft, from which it will be thrown by centrifugal force in a fine spray, which is sucked into ventilating ducts, to permeate the entire machine. Oil tends to rot insulation. It also forms, with dust, a sticky mud, which, besides tending towards electrical breakdown by the formation of a leakage path, also reduces the effective ventilation, both by clogging up the ducts, and by the formation of a heat-insulating film over both iron and windings. Defective oiling provides a four-fold source of potential breakdown, and once it is allowed to develop, the trouble is almost impossible to remove without completely dismantling the machine.

The correct oil level, when established, preferably with the motor at rest, should remain sensibly constant for long periods. If the level drops rapidly, it is a sign that bearing leakage is taking place, and that the bearings need attention. The level will, of course, be lower when the machine is running, but should return to normal after it has been shut down for some time.

The correct procedure for a plain bearing machine, which is free from bearing leakage, is to clean out the reservoir, and renew the oil whenever it becomes dirty. This, under ordinary circumstances, should not be needed more than

once a year. Very occasionally the reservoir should be topped up to the correct level, as shown by the gauge. Any further lubrication is just "oiling the windings," and should be avoided at all costs.

3. Sleeve bearing failures may occur through under-lubrication arising from low oil level, or sticking rings. The prevention of the first is obvious. Rings may stick through gummy oil, grit, or mechanical imperfections. Where rings are bent up from strip, instead of being machined from the

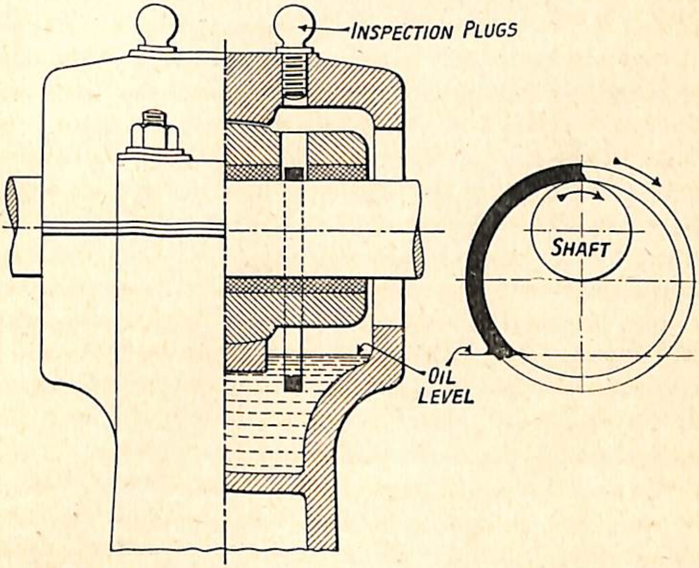

Fig. 1.—Part section of pedestal sleeve bearing, showing action of oil ring

solid, make sure that the ends at the joint are smooth, and that the joint is no wider than the rest of the ring, as it might then stick in the slot. Another possible cause of trouble is the ring actually jumping out of its slot, owing to bad vibration. A cure for this is to fit a small strip of metal over the slot, giving sufficient clearance to prevent the ring jamming. If the machine has a removable inspection cover

or plug, it is a good thing to take a look at intervals to see that rings are working properly.

A method of detecting oil leakage which is not serious enough to show up easily, is to paint a light-coloured band on the pedestal or end-shield. This may be either light buff or yellow, or better still, whitewash, which will show traces of oil which would be almost invisible on the dark paint usually used for machines.

Ball and Roller Bearings

Ball and roller bearings should require even less attention than sleeve bearings. As the treatment of both ball and roller bearings is identical, the expression " ball bearings " throughout the following notes refers also to rollers.

As in the case of sleeve bearings, the essence of correct lubrication is to use the right stuff, and the right amount of it. Oil is very seldom used for ball bearings, its place being taken by grease.

IMPORTANCE OF CORRECT GREASE. Grease, being a mixture of oil suspended in a vehicle of a soapy nature, may fail in two ways, if of inferior or unsuitable grade. It may *oxidise*, which means that it goes gummy and causes the cage or balls to stick. This spoils the rolling action of a ball race, and introduces sliding friction, causing rapid wear.

The other type of failure is *separation*, in which the oil is squeezed out, and runs away, leaving the soapy base, which promptly dries to a hard residue. This actually has an abrasive action on the race, and is in fact, little better than grit. Separation may occur even with good grease, as discussed later.

Another possible trouble may be caused by impurities in the grease, resulting in corrosion of the race by chemical action.

OVER-GREASING. A bearing filled full of grease will suffer from " churning " which sets up overheating, and will probably lead to separation of the grease, and its attendant

troubles, even with good quality grease. No bearing should ever be filled more than two-thirds full, as the grease expands when running, due to the churning action. An exception is sometimes made in the case of low-speed machines which are to run in very dirty situations, when the quantity of grease is increased to exclude grit. This is very exceptional, however, as most machines are fitted with dust-excluding washers, and even special containers for the races.

Normal practice is to grease twice a year, with the quantities recommended by the machine makers, some of whom supply a grease gun with removable key, so that casual greasing cannot be undertaken by unauthorized persons. In the absence of special instructions, approximate quantities for average machines would be from $\frac{3}{4}$ oz. for a 1 in. shaft bearing to 2 oz. for a 2 in. shaft.

The importance of excluding dirt from ball races cannot be over-emphasized. Owing to the fine clearances allowed, hard grit will actually embed itself in the surface of both balls and races, and rapid wear will result. It should be borne in mind that a ball bearing which once commences to wear, deteriorates very rapidly, and may actually disintegrate and wreck the machine. Even soft metal dust (i.e. brass or copper), will cause undue wear. Precautions to be taken include the careful re-assembly of any dust-excluding devices when the machine is dismantled, and ensuring that, when greasing, both the gun and the nipple are perfectly clean.

If, by any chance, dirt does enter the bearing, it must be removed, along with all old grease, by dismantling and *thoroughly* washing in petrol (*not* paraffin) until every trace is removed and the bearing rotates freely, without any sticking.

Oil lubrication of Ball Bearings

Occasionally a high-speed machine is designed to run with oil lubrication, usually with the lower part of the race

dipping into a reservoir of oil. In such cases, the oil should be maintained at the correct level, and the makers' recommendations followed implicitly. A point worth bearing in mind with this type, is that if the machine has to stand idle for long periods, the oil will gradually drain away from the upper part of the race, leaving it exposed to rusting, which will lead to excessive wear, and premature failure. To guard against this, the rotor should be given a turn or two by hand, every two or three days.

Other Causes of Bearing Troubles

Thrust Loads. Unless a motor is designed for vertical running, or other special service, and is fitted with thrust bearings, it will not take thrust loads. This particularly applies to ball bearings, which allow no end play and will wear badly under thrust loads. A sleeve bearing machine allows some end play, but an excessive thrust may cause the shoulder on the shaft to rub against the end of the bearing.

Thrust loads may inadvertently be applied in the following ways :—

1. Incorrect mounting of direct-coupled machines.
2. Bad alignment of belt pulleys.
3. Bad assembly of the machine, with the rotor in the wrong position on the shaft, or the ball races in the wrong position, or not bedding properly in their housings, due to dirt. All of these cause the rotor to be displaced horizontally in the stator tunnel. Trouble will develop due to the magnetic pull trying to centre the rotor again, thus setting up thrust loads.

Tight Belts. A really tight belt, due to miscalculation when installing, or subsequent shrinkage, provides a very bad sideways pull, and, with an overhead drive, may actually transfer the load from the bottom of a sleeve bearing to the cap which, having oil grooves, is not intended to take such loads. There is no need for belts to be exceedingly tight, and tightening beyond a certain amount is no cure for slipping.

Slack off the belt, and use a good surfacing compound, such as "Cling-Surface," which will be far more effective, and save a lot of power, bearing wear, and, in extreme cases, a bent shaft. Incidentally, it is worth remembering that if a drive can be arranged so that the slack side is on top, it will give a greater contact angle, and transmit more power without slipping, for the same tension (see fig. 2).

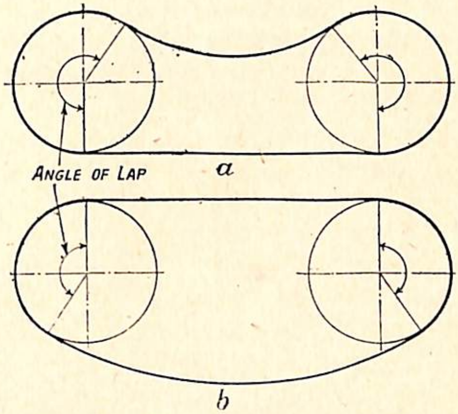

Fig. 2.—Showing difference (exaggerated) in contact area between belt and pulley. (*a*) slack on top; (*b*) tight side on top

BAD ALIGNMENT OF MACHINES. Machines coupled with rigid couplings may suffer from excessive wear due to shaft distortion caused by mis-alignment at the time of erection, or subsequent settling of foundations. When checking alignment, remember that for two shafts to rotate smoothly, the distance between their coupling faces *must* be the same for any given point on the coupling, at any part of a revolution. Assuming that the coupling faces are true (which can be independently checked), the clearance between the coupling faces should be the same all round. This can be checked with a feeler gauge. If a dial indicator (or dial micrometer) is available, a complete check can be carried out as follows :

1. Check each half-coupling separately, by mounting the indicator either upon a floor stand, or on a bracket clamped to the machine itself, so that the foot of the indicator touches the periphery of the coupling as shown in fig. 3, or on the other half-coupling (fig. 4). Rotate the machine by hand, and see that the reading is the same all round. Now check the coupling face, in a similar manner. If untrue, the complete shaft and coupling must be trued in a lathe. In the case of avery large machine, it may be possible to improvise a rest to hold a tool or portable grinder, and true up with the machine running.

2. Adjust the machines so that the coupling faces are approximately parallel and concentric. The two couplings

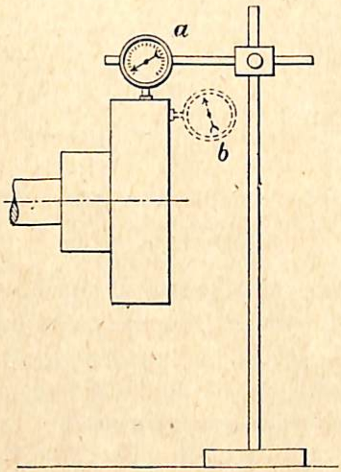

Fig. 3.—Checking truth of single half-coupling with dial indicator. (*a*) **periphery** ; (*b*) **face**

should be in the correct relative positions (bolt holes in line). Insert a feeler of suitable thickness at four points round the coupling, and adjust one machine until equal readings are obtained at all four points. Turn one machine through half

a revolution, re-check, return it to its original position. Repeat with the *other* machine turned through half a revolution. If the readings are still the same all round the faces are absolutely parallel.

3. To set the two couplings concentrically, fix a dial indicator to one coupling by a clamp (fig. 4), with its foot

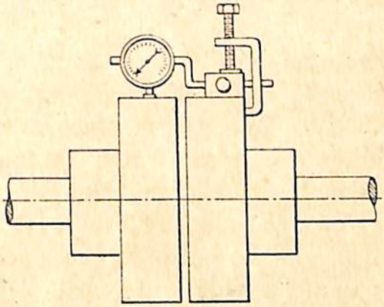

Fig. 4.—Checking concentricity of two half-couplings with dial indicator

touching the periphery of the other. Revolve this machine, and adjust until the reading is the same all round, taking care that the parallelism previously obtained is not lost. The holding-down bolts may now be tightened.

VIBRATION. The hammer-blow action of a vibrating machine will ruin bearings, particularly roller or ball type. If vibration is due to mechanical unbalance, the machine should be rebalanced by the makers, unless there is some simple explanation. If vibration develops suddenly, an immediate investigation should be made. A fruitful source of vibration is the misalignment of machines already discussed.

Worn bearings are another cause of vibration, which, in turn, will cause increased wear.

Vibration, if of any magnitude, must be promptly checked. It is not only bad for bearings, but will ruin commutation on d.c. machines, and ring contact on a.c.

The running of a variable speed machine at speeds considerably above the designed maximum will cause vibration trouble, particularly in the case of old machines with "whippy" shafts. Critical speeds may be approached, when the vibration suddenly increases to an amount out of all proportion to the speed increase. A machine allowed to run at a critical shaft speed may be completely wrecked.

Bearing Currents

These are caused by the shaft attaining sufficient potential above the earthed frame of the machine to break down the oil film, and allow a current to flow through the bearing. They may be due to unbalanced magnetic fields inducing currents in the shaft, or to an earth fault on one of the rotor conductors, when another point on the machine is already earthed. They cause pitting and burning of both bearing and shaft, and can only be cured by insulating the bearings if the trouble is due to faulty design. A suggestion has been made that an earthed brush, rubbing lightly on the shaft would prevent trouble, by offering an easier path than through the bearing. This might be tried on a machine which suddenly develops sparking at the bearings, but cannot be shut down immediately for investigation.

Effect of Bearing Wear

The chief effect of bearing wear, in addition to vibration and similar troubles, is to alter the position of the rotor in its tunnel, i.e., it will reduce the air-gap on the side upon which wear takes place. This leads to an unbalanced magnetic pull on the rotor, tending towards even greater bearing wear, and in extreme cases, to shaft distortion, especially in machines of old design, with shafts of insufficient stiffness. The effect of wear and increased pull, even without shaft distortion, will be to reduce the air-gap by a dangerous amount, particularly in the case of induction motors, where the gap is small to start with (about 0.01 in. in the average

5 h.p. motor), when the rotor may " pull over," and grind against the stator. Air gaps should be regularly checked as a matter of routine, a feeler gauge being inserted at four points around the tunnel, on the *driving side*. One point must be the direction of maximum wear, which with a belt drive will be in the direction of the belt.

Pulling-over is more likely to occur with sleeve bearings, than with the ball or roller type, which are less liable to wear sufficiently, without giving previous warning in other ways. A worn ball or roller bearing clicks and rattles in an unmistakable manner.

Bearing Repairs

Sleeve Bearings. Bearing seizure varies according to the metals employed. A bearing lined with white metal may " wipe," or melt and run out quietly, without damage to the shaft, although it will probably allow the rotor to pull over. A sleeve of brass or bronze, unlined, will probably seize up solid, and may cause shaft scoring. If this is only slight, the shaft may be skimmed or lightly ground, and new brasses fitted with a slightly smaller diameter. (Remember that the pulley, pinion or coupling will also require bushing, if the fault is on the driving side.)

If the scoring is of such depth that the shaft would be weakened by turning, the only course open, unless a new shaft is fitted, is to have the scored portion built up by welding, and then machined to the original diameter. This should only be attempted by a skilled welder.

A bronze or brass bush will probably be completely ruined, and will have to be replaced. Bushes lined with white metal, may be replaced if spares are carried, or, if machining facilities are available, they may be re-lined, as described in the following notes.

Re-Lining White Metal Bearings. Let us imagine that a machine with split-type bronze or brass bearings lined with white metal has " run-out." A lathe is available,

together with a blow-lamp, and the usual workshop odds and ends. We require to re-line the bearings, the shaft being undamaged.

The first step is to melt out all the old metal with a blow-lamp, leaving the bush clean and bright. Next, carefully tin the surfaces to be metalled, using " killed " spirits, or other reliable flux, and tinman's solder.

Next make up a fixture for casting. Fig. 5 shows one method, for dealing with one half at a time. A bent plate acts as the body of the fixture, and the half-bush is clamped to the vertical face. A dummy half-shaft, either sawn from rod slightly *smaller* than the actual shaft, or bent up from sheet metal, is coated with french chalk or smoked in a candle flame to prevent sticking, and is also clamped to the vertical plate, care being taken that it is truly concentric with the bush. Clay luting is placed round the edges to prevent leakage and a small wall of clay about $\frac{3}{4}$ in. high is placed round the top of the bush, to provide an additional head of metal.

The metal should be bearing metal of a good brand, clean and new (do not use the old metal again) and should be melted in a clean ladle. It should be heated only sufficiently to ensure free running, as it can be ruined by overheating. A rough test for the correct temperature is to dip a small slip of white paper into the metal ; the paper should brown, but not blacken or burn. Do not heat more metal at a time than is likely to be required, as metal constantly re-heated is liable to be spoiled. Stir well, to avoid separation of the different metals in the alloy.

Heat the bearing shell with a blow-lamp until the tinning is just about to run, and pour in the molten metal in a steady stream, holding the ladle close to the job to avoid splashing. Fill up to well above the top of the bush, in order to have a good head of metal and so exclude air-bubbles.

When cool, remove from the fixture and repeat the process with the other half, trim off the surplus metal with a hacksaw,

smooth off the edges and machine the bore in a lathe, allowing a clearance of 0.01 in. for every 1 in. of shaft diameter.

Oil grooves must now be cut in the top half, or cap. As previously stated, grooves must never be cut in the half of the bearing which takes the load, as they would merely break up the oil film, and invite seizure. The grooves should be cut on the lines of those in the old cap, or if it was too badly damaged to trace them out, cut them as shown in fig. 6, which shows a suitable arrangement for single and double ring bearings. No groove should run out at the edge

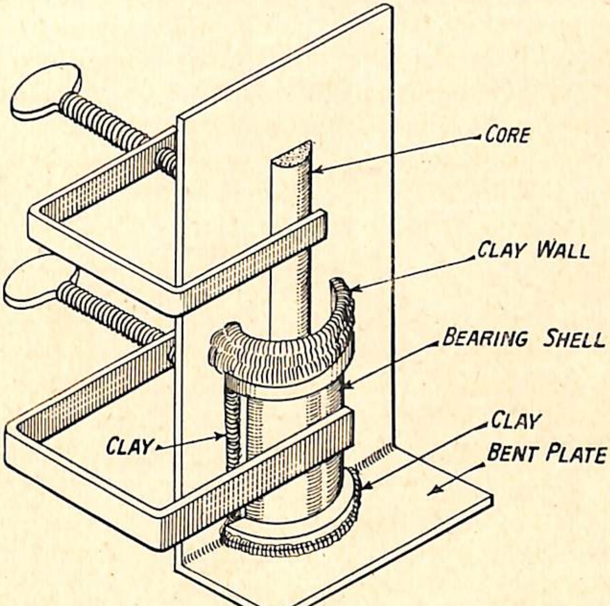

Fig. 5.—Fixture for re-metalling bearing shells

of a bearing ; their purpose is to distribute the oil on the shaft, not to act as auxiliary leaks. Cut them with a round nose chisel, and give them gently rounded edges ; sharp edges will only scrape the oil off again. Cut the hole or slot communi-

cating with the oil ring groove in the outside of the shell ; take a last look round for any sharp edges or burrs, and reassemble the motor. Do not forget on double ring bearings, to slip the inner rings on to the shaft first, or you will have to do it all over again. Remember that the bearings are dry, and feed some oil in from a can before starting up the motor again, or it will seize up before the rings can feed it sufficient. If there has been a seizure, the oil wells should have been cleaned out with petrol, and refilled with new, clean oil.

The casting fixture described above is, of course, only one method of doing the job. A number of other ways will probably occur to you. For instance, it is possible to cast both halves together by recessing the two shells (with a slight gap between them) into a block of wood, which has a further recess to take the dummy shaft.

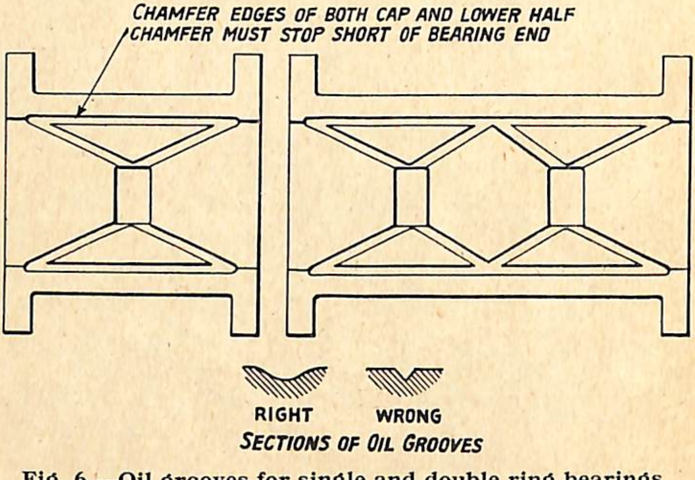

Fig. 6.—Oil grooves for single and double ring bearings (diagrammatic only)

Replacement of Ball and Roller Races

There is no question of repairing ball and roller bearings ; they must be replaced with new units identical with the old ones. When putting the new bearing on the shaft, remember

that in order to prevent "creep," the inner race must be a tight fit on the shaft, and that ball races are very accurate and delicate things. Do not, therefore, drive the new bearing on to the shaft by whacking the outer race heartily with an iron bar. Take a piece of pipe, slightly larger than the shaft, slip it over the end and drive on the inner race. Any amount of brute force may, of course, be used on the old bearing to remove it, providing that the shaft is not damaged. With small motors, the easiest method is probably to hang the rotor by the bearing on two metal strips supported between two blocks of wood, and tap the shaft end with a piece of copper and a hammer.

When re-assembling, make sure that the housings for the outer races are clean and free from grit, or binding, due to distortion and thrust loads, will occur.

APPROXIMATE FULL LOAD CURRENTS OF MOTORS OF VARIOUS H.P. RATINGS AT SOME COMMON VOLTAGES

	110 volts			230 volts			400 volts			440 volts		
H.P.	D.C.	Single phase	3-phase	D.C.	Single phase	3-phase	D.C.	Single phase	3-phase	D.C.	Single phase	3-phase
¼	3.5	4.6	2.5	1.7	2.3							
½	5.7	7.6	4.1	2.8	3.7	2	1.6	2.2	1.2	1.4	1.9	1
1	10.5	14	7.5	5	6.7	3.6	3	4	2.1	2.6	3.5	1.9
2	18	24	11.5	8.5	11.3	6.5	5	4.7	4.7	4.5	6	3.3
5	42	56	30	20	26.5	14.5	11.5	15.3	8.3	10.5	14	7.6
10	80	107	58	38.5	51	27.5	22	29	15	20	26.5	14.4
20	155	—	114	75	—	55	43	—	30	39	—	28.5
50	376	—	278	180	—	133	105	—	77	95	—	70
100	740	—	525	354	—	250	205	—	140	185	—	130

The above values are *approximate*, as the current taken by a motor of any given h.p. depends upon many factors. The figures will, however, be useful for calculating cable sizes, fuse wire ratings, etc. Figures are given for induction type a.c. motors based upon an average power factor of 0.8 for 3-phase motors, and 0.75 for single-phase, except in the very smallest sizes, which are slightly lower.

CHAPTER II

GENERATORS
(Commutators and brushgear)

Successful commutation, one of the most important factors in the operation of d.c. machines, depends upon several factors, any one of which may cause poor running if overlooked.

Brush Holder

Although there is an almost infinite variety of designs of brush holders, the general principles are similar throughout, and all consist essentially of a rectangular box to hold the brush, together with a device for applying spring pressure to the top of the brush, the pressure being variable for purposes of adjustment, and to compensate for brush wear. In a well-designed brush holder there will be very little pressure variation throughout the life of the brush.

Points to note about the brush holder are :—

1. It should not be rough internally, causing the brush to bind.

2. It should not be so worn that the brush fits sloppily, or bad chattering will result.

3. The position of the brush holder must be correct, being truly at right angles for radial brush holders, or inclined at the correct angle in the case of trailing or reaction holders. For trailing holders, the angle should be about 10° from the radial, in the direction of rotation, and for reaction holders about 35° *against* the direction of rotation (fig. 7).

4. The brush holder should approach within about $\frac{1}{8}$ in. to $\frac{1}{4}$ in. of the commutator if chattering is to be avoided.

If bad chattering is experienced with radial brush holders,

try setting them with a very slight trail, providing that the machine is non-reversible, as an ordinary trailing or reaction holder is not suitable for reaction running. Do not forget that altering the angle of the brush holder will necessitate re-bedding the brushes.

Brushes

The points to be watched regarding the brushes themselves are : 1, Grade of brush ; 2, Good bedding ; 3, Correct fitting and pressure ; 4, Cleanliness.

1. Correct Grade. The importance of selecting the correct grade of brush cannot be over-emphasized. Brushes are made in a very large number of grades, from the hardest carbon to the softest graphite, as well as in innumerable grades of a mixture of copper and carbon. Each has its own distinctive characteristics, and only approximate rules can be laid down as to their selection. Where the machine

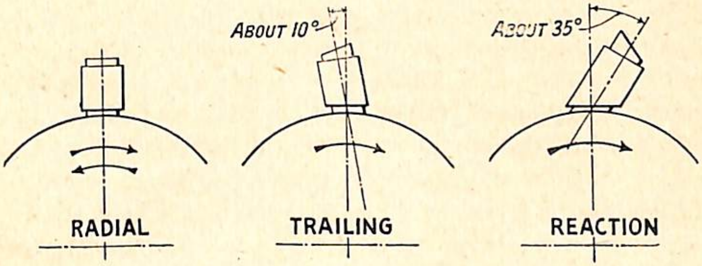

Fig. 7.—Usual types of brush-holders

manufacturer recommends a particular grade his advice, based upon years of experience, should be adhered to. Where information is not available, the recommendations given on page 101 may prove helpful.

The *mixing* of brush grades on one machine must be shunned like the plague, as the use of even one or two wrong brushes on a machine is far worse than completely equipping it with incorrect brushes. The unequal brush resistances

will completely upset the distribution of current between the brushes, sometimes sufficiently to cause disintegration of the brushes or even burned-out pig-tails.

2. Correct Fitting and Pressures. The brush should be a good sliding fit in the holder, and should neither jam nor rattle. This should be checked up when warm, as the brush will expand on heating. The pigtail should be brought out so that it does not kink or jam, or exert any effort on the brush which may upset the correct pressure. The correct pressures for various grades are given in Appendix 1, but a good rule is 2 lb. for every sq. in. of brush area. Pressures should be tested by hooking a spring balance to the pigtail, and measuring the pull required to release a piece of paper placed between the brush and the commutator. Take two or three readings, varying the angle of pull slightly, and work on the smallest of the readings.

3. Bedding-In. Brushes are sold with either flat ends or, in the case of those specially produced for a particular machine, with the ends roughly shaped to the correct radius. In either case, they must be carefully bedded to the commutator surface. This is done with a piece of fine glasspaper between brush and commutator, pulled backwards and forwards until the operation is almost complete. The final bedding should be done *one way only* (in the direction of rotation). Care should be taken to use a long strip, and keep it close to the commutator (see fig. 8), to avoid rounding the edges of the brush. An exception to the general rule that brush edges must not be rounded is made in the case of reaction brushes, when the leading edge should be brought to a slight radius, to avoid chattering due to a sharp edge catching in the commutator slots where the mica is undercut. Spring pressures should be increased to the maximum for bedding in.

An alternative method consists of applying a " bedding stone " to the commutator, while running light. The abrasive removed from this is carried by the commutator,

and wears away the brushes to the correct profile. Careful cleaning of both commutator and brushes is essential after using this method.

Brush bedding is long and tedious work, and if there is a great deal of this work to do, it may pay to make up a gadget for rough work, consisting of a hardwood drum, the same size as the commutator, covered with glasspaper, and driven by a small motor A dummy brush holder is provided at the correct angle, and the brushes are ground to the correct radius, being afterwards finally bedded in the usual manner.

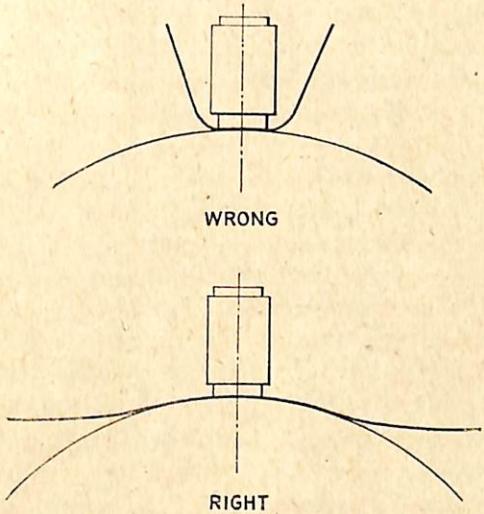

Fig. 8.—Method of bedding-in brushes to avoid rounding edges of brush

Whatever method is used, the machine should be given several hours no-load run to complete the operation, before being put once more on normal duty. When fitting new brushes the commutator should be polished.

4. Cleanliness. Brushes, and brush gear must be kept clean. If grit is allowed to get underneath the brushes, it

will cause bad sparking, and possibly scoring of the commutator. If it is noticed that pigtails have a tendency to corrode, they may be tinned. All contact surfaces, terminals, and bus-bars of the current-collection system should be kept clean and tight.

Commutators

No amount of attention paid to brushgear will be the slightest good if the commutator itself is in poor condition. A commutator in good running order should have a " skin " of a rich brown colour, and should run without sparking, or with only pin-point sparking up to the full load capacity of the machine.

Commutation troubles show themselves either as heating or sparking. Overheating, without sparking, is caused either by too high a brush pressure, giving rise to undue friction losses, or too low a pressure, or incorrect brush grade, giving rise to high contact voltage drop, and high watts loss at the commutator surface.

Sparking may be due to either electrical or mechanical faults, and should be investigated as follows :—

Mechanical Faults

These include 1, General eccentricity of the whole commutator. 2, High spots. 3, Low spots or " flats." 4, Rough surface (including grooving). 5, High Mica.

1. General Eccentricity. This, as may be imagined, is not very common, but might occur in an old machine through shaft whip, or similar causes. The obvious remedy is to true up in a lathe. It should be remembered that eccentricity is a relative term, but only a few thousandths of an inch can be allowed, particularly in the case of high-speed machines.

2. High Spots. These can be caused by loose segments. " Loose " is again a relative term, and it must not be imagined that a " loose " segment can be moved with the

fingers. In a commutator which is not tightly clamped, however, it is possible that one segment might be loose enough to rise slightly under the considerable centrifugal forces, and cause a high spot. A high spot can usually be recognised from the character of the sparking, which will be intermittent, and not continuous, as it will cause the brushes to jump at one point of the revolution, and the commutator to burn at one point only. The loose segment will probably be immediately in front of the burned one. Tighten the commutator bolts before truing, with the commutator warm.

3. Low Spots or Flats. These are usually caused by the brushes jumping, either from surface roughness, or through a high spot. It follows that a machine which suffers from high spots will also develop flats, if not attended to promptly. The only remedy is to true-up in a lathe.

4. Rough Surface. This may develop from any fault which causes sparking. The trouble is cumulative, since the rougher the surface, the worse the sparking. The cure is discussed in a later page.

Grooves around the periphery, of brush width, are caused by brushes of the wrong grade, or excessive spring pressure, although any machine will groove in time, if the brushes all bear in the same paths. This is usually avoided by staggering the brushes, so that their tracks overlap or, in the case of large machines, by arranging an " end play " device, so that the armature has a regular horizontal movement, spreading the wear. Old machines with copper gauze brushes may develop a definite " waist " on the commutator, and it may be worth while, if they are to be kept in service, to convert them to copper-carbon brushes, which will, of course, involve new brush gear.

Serrating of the commutator is grooving of less than brush width, due to grit under the brushes, and will not occur on machines that are properly maintained.

5. High Mica. This is caused by the use of mica which is

too hard to wear at the same rate as the copper, and so stands proud of the surface, probably not sufficiently to be seen by the naked eye, but still sufficiently to cause trouble. The remedy is *undercutting*, as discussed later.

Electrical Faults

Assuming that the commutator and brushes are in good condition, sparking may be caused by (1) excessive overloading; (2) wrong position of brush rocker; (3) a fault in the machine windings.

1. Excessive Load or Speed. Little need be said about this ; if a machine sparks when overloaded or run overspeed, do not overload it. A machine is meant to give a certain output, and that is marked on its nameplate. If you consistently try to get more out of it than this, you will only lay up trouble for yourself, unless the machine was very much underrated in design. This was occasionally the case in some old machines, but does not occur nowadays.

2. Wrong Position of Brush Rocker. The whole principle of commutation is based upon the assumption that the coil which is connected to the segment under the brushes should not be cutting flux ; i.e., that it should not be under a pole shoe, but in the gap between the two poles. Theoretically, the " neutral axis " is midway between the two poles, but this will not be in the correct position for the brush rocker, due to the pitch of the end connections on the armature. The position may be found by selecting an armature slot which is midway between the poles, and tracing out along the armature end connections to its appropriate commutator bar, which should, in theory, lie right under the centre of the brush. In practice, this will only be the correct position if interpoles or " compoles " are fitted, or if the machine is reversible. If there are no interpoles, and the machine is to run in one direction only, the best position of the rocker is a few degrees *forward* (i.e. in the direction of rotation) of the neutral position, for generators, and a few degrees

backwards in the case of motors, owing to the field distortion produced by armature reaction. Brush rockers are often fixed or marked, to avoid the necessity for this experimenting. There are several methods of finding the neutral axis by experiment, one of which is as follows. With the machine stationary, and the field excited from a separate source to a low value (not more than half normal) a voltmeter is connected across the brush arms, and the field switched on and off several times.

If the brushes do not lie in the true neutral axis, a kick will be observed on the voltmeter every time this is done. A field switch must, of course, be used (see page 36).

It must be realised that this shows the true neutral axis for no-load running, and that if the machine is not fitted with interpoles the best running position may differ slightly from that given above. Possibly the very best method of all is to "see how it runs."

3. WINDING FAULTS. Either a short-circuited or an open-circuited coil on the armature will cause commutation troubles. The detection and cure is dealt with in a later section.

Another fault, admittedly not common, but which has happened, particularly after a machine has been dismantled, is wrong connection of the interpoles, which if reversed, hamper commutation instead of assisting it.

COMMUTATOR MAINTENANCE. As previously mentioned, excessive roughness or pitting, eccentricity, scoring or deep grooving, require the commutator to be trued, in a lathe if the machine is not so large as to make this impracticable. It may be turned or ground. If turned, use a very sharp tool (diamond for preference), take very light cuts, and watch for the danger of the tool "digging-in," or you will need a new commutator. Cover the armature end windings with a wrapping of cloth or stout paper, secured by a few turns of wire, to exclude copper dust.

In the case of large machines, a special commutator grinder is used, consisting of a motor-driven wheel mounted on a

slide-rest mechanism, which clamps on to the bearing pedestal or bracket. The brushes should be raised, and the machine rotated by an external power source.

SMOOTHING of the surface can be carried out with a commutator stone, which has a surface of the correct radius, and is held against the surface of the commutator as shown in fig. 9. For high voltage machines, the brushes must be raised, and the machine rotated by external power, but medium and low voltage machines may run under their own power. In either case, after stoning, the machine must be shut down and all dust carefully blown out and the brushes

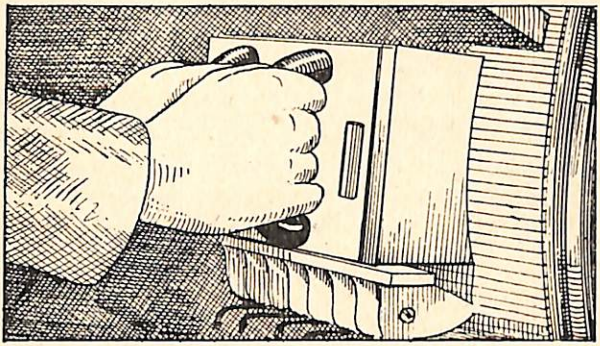

Fig. 9.—Grinding commutator

cleaned. If a proper stone is not available, make up a hardwood block to the correct radius, and cover it with fine glasspaper.

UNDERCUTTING. Mica may be undercut with a special undercutting machine, if the amount of work handled justifies the expense, or by hand, with a piece of machine hacksaw blade, fitted with a wooden handle as shown in fig. 10. Make sure that all mica is undercut, and that you do not merely cut a slot down the middle leaving the edges still proud (fig. 11). Undercut about 1-16th in. only, or less

in smaller machines, and bevel off the edges of the segments with an old smooth file. Undercutting requires care, as a sharp instrument carelessly jabbed into the end windings will not improve the machine. Clean away all dust afterwards. (Undercutting is not a practical proposition for very small machines.)

After undercutting, brush chatter may occur. Lubricate the commutator with a *single touch* of solid paraffin wax, while the machine is running. This is the *only* lubricant which should ever be used. Do not use vaseline, or any kind of grease, and be sparing with the wax, the thinnest film suffices. Let it be pure paraffin wax, and not an old candle end, which may contain acids which will cause corrosion.

Slip Rings. Many of the troubles and cures discussed above will be applicable to slip-rings which sometimes suffer

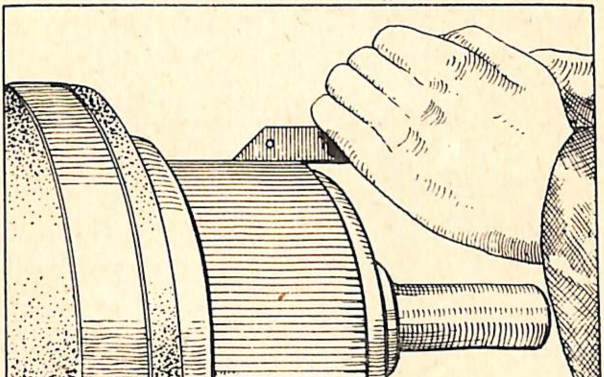

Fig. 10.—Undercutting mica

from sparking or overheating due to the same causes: vibration, flats (due to inconsistency in the metal), or grooving due to grit or unsuitable brushes. The remarks concerning the mixing of brush grades also apply, together

with those regarding the importance of correct bedding and fit of the brush-holders.

Slip-rings should develop a polished surface ; if it is rough or pitted, there is something wrong. There is one other peculiarity which sometimes occurs. On alternators, etc., where the rings carry d.c. to a rotating field system, it may be found that the positive ring becomes polished, while the negative ring becomes dull or rough. This is due to minute particles of metal being transferred from the ring to the brush. To counteract this, the connections may be periodically changed over, so that the positive ring becomes negative, and vice versa, thus equalizing the wear.

Conclusion. There are two golden rules to be borne in mind :—

1. If a commutator or slip-ring sparks badly, do something about it before the damage is serious. An immediate shut-down may be inconvenient, but to delay it may mean a much larger and more expensive one later.

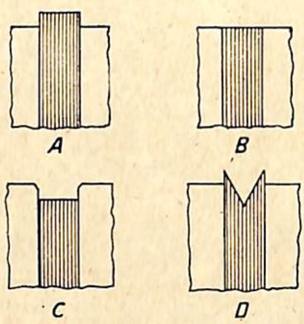

Fig. 11.—Exaggerated view of commutator mica. (*a*) high mica ; (*b*) flush mica ; (*c*) mica properly undercut and edges of segments bevelled ; (*d*) poor undercutting

2. If a commutator or ring is a good colour, nice and smooth, and runs sparkless or with only the most minute pinpoint sparking, up to full load, *leave it alone.* Don't get

" sandpaperitis " (which is as bad as " oilcanitis "), and give it a wipe just for luck, every two or three days. Do not on any account use emery paper. A hard abrasive becomes embedded in the metal or brushes, and causes scoring.

CURRENT-CARRYING CAPACITY OF SOME COMMON SIZES OF V.I.R. CABLES BUNCHED TOGETHER AND RUN IN CONDUIT.

(Extracted from the 1939 Regulations, by permission of the Institution of Electrical Engineers).

Nominal area	Stranding	Permissible current in amps. for the number of cables stated				
		2 cables	4 cables	6 cables	8 cables	10 cables
.0015 sq. in.	1/.044 in.		5		5	
.002 ,,	3/.029 ,,		5		5	
.003 ,,	3/.036 ,,		10		8	
.0045 ,,	7/.029 ,,		15		12	
.007 ,,	7/.036 ,,	29	23	20		17
.01 ,,	7/.044 ,,	38	30	27		23
.0145 ,,	7/.052 ,,	45	36	32		27
.0225 ,,	7/.064 ,,	56	45	39		34
.03 ,,	19/.044 ,,	65	52	46		39
.04 ,,	19/.052 ,,	78	62	55		47
.06 ,,	19/.064 ,,	102	82	71		61
.1 ,,	19/.083 ,,	147	118	103		88
.15 ,,	37/.072 ,,	189	151	132		113
.2 ,,	37/.083 ,,	229	183	160		—
.3 ,,	37/.103 ,,	298	238	—		—
.4 ,,	61/.093 ,,	358	286	—		—
.5 ,,	61/.103 ,,	413	330	—		—

This does not apply to all situations in which cables may be used, but applies to the wiring of buildings. Currents are based upon permissible temperature rise, and in many cases a larger size of cable than that given above may be needed as the voltage drop permissible may be the limiting feature.

CHAPTER III

GENERATORS AND MOTORS
(Windings)

Winding faults are due to one of two causes :—

1. Insulation breakdowns due to moisture, dirt or defective insulation.

2. Insulation breakdowns or severed conductors due to mechanical damage.

It is not feasible in the limited space of this book, to give a full account of the different types of faults possible with all types of machines, and it is proposed therefore to confine the scope of this section to practical methods of recognizing the more common types.

There are three main types of faults :—

1. Faults to earth or to the core of the machine.

2. Short-circuits between turns. (Obviously, two separate earth faults will give the effect of 1 + 2, i.e., earth fault and short-circuited turns.)

3. Broken conductors, causing open-circuited coils.

Location of Faults

It is assumed that, to carry out this work you will have available an insulation resistance tester and also voltmeters and ammeters of suitable range, or a universal testing set.

D.C. Machines

Earth Fault. Test for resistance between the machine terminals and the frame. If " down," there is an earth fault on the machine. Disconnect the shunt field circuit from the armature, and test separately (1) field to frame, (2) one brush to *shaft* (not frame, or you will include the bearings in the

circuit). You now know whether the fault is on the field or the armature. If it is on the field, the approximate location may be found by disconnecting the field coils, and testing each one separately. If the armature is at fault, first lift the brushes clear, and try again from one commutator segment, to make sure that the earth does not lie in the brush-gear, due to a coating of carbon dust, or a pigtail touching one of the rocker supports. If the fault is definitely on the armature, the only way to locate the actual coil is to unsolder the leads from the commutator, and test each coil separately. Do not forget to test each commutator segment as well, as it is possible that one of these is the culprit. Also, test each coil as soon as both ends have been disconnected, instead of disconnecting them all first ; you might be lucky and find the faulty coil soon, in which case you will have saved a lot of unnecessary work.

" Smoking " Faults. Another method, which must be used with discretion, is commonly known as " smoking " a fault. It is based on the fact that the earth fault is usually a pretty bad contact, i.e., it will heat up rapidly with much less than full load current flowing. A source of current, with plenty of series resistance to limit the value, is applied between winding and core and the current brought up from a very low value, until smoke or sparks appear at the fault. Great care is necessary not to leave the current on too long, or to use too high a value, or extensive damage will result.

Fields

Open circuits can only be located by carrying out a continuity test on each coil separately, either with an I.R. tester or with a test lamp.

Short-circuited turns can be located by passing current through the field, and measuring the voltage drop across each coil in turn ; the one showing the least voltage across it is the one containing the short-circuited turns.

Incidentally, the greatest care must be taken when carrying

out tests on a field system, particularly on a machine of any size. If current is to be passed through it, a proper field switch and discharge resistance should be used to control the current as shown in fig. 12. If this is not available, then use two ordinary switches, connected as in fig. 13, the second switch being connected in series with a resistance of approximately the same resistance as the field. Close the second switch before opening the supply switch, so that the field may discharge through the resistance.

If testing with a lamp, do not light-heartedly "flash" test leads on the ends of field coils. A d.c. field system is very

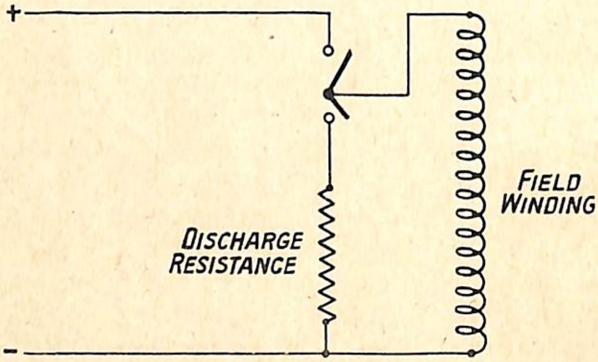

Fig. 12.—Connections for field switching with make-before-break field switch and discharge resistance

highly inductive, and if the current is suddenly interrupted will give momentary voltage "kicks" often amounting to several thousand volts, which may cause breakdown to earth of a previously sound field system, and, if the investigator is unfortunate enough to play (quite unintentionally) the part of a discharge resistance, he will receive a serious shock.

Armatures

Assume for the sake of simplicity that the armature of a 2-pole machine is faulty. Connect a source of current (say

an accumulator and series resistance) to two opposite segments of the commutator. If accessible, this may be done with the armature in position, by connecting to the two brushes, but take care that the current is kept low (less than $\frac{1}{4}$ of full load) or the machine may start to revolve, due to residual magnetism. If the armature has been removed from the machine, place the wires against the appropriate commutator segments, and hold them in position with a couple of turns of empire tape, with a lashing of sticky tape on top. Do not use sticky tape directly on the commutator, as it will make the surface dirty. With current passing, measure the drop between adjacent segments all round the com-

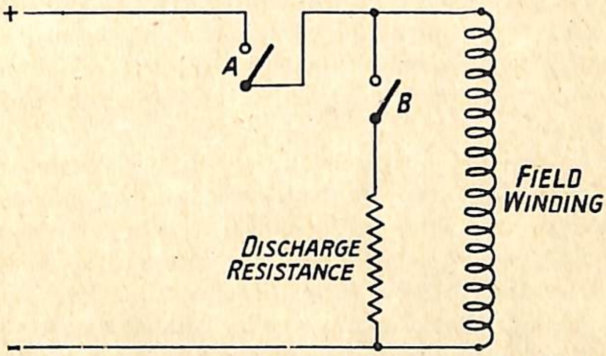

Fig. 13.—Connections for field switching with two plain switches. B must be closed before A is opened

mutator, using a low-reading voltmeter. All the drops should be equal. If one is lower than the others, the coil is shorted, or at least has some short-circuited turns. A very high " kick " indicates an open circuit. (See fig. 14.)

If the machine has more than two poles the leads should be clamped to segments one pole-pitch apart, i.e. 90° for a 4-pole machine, 60° for a 6 pole, etc.

A.C. Machines

For these machines the same general type of tests are applied, your own common sense telling you which are

applicable. The rotating fields of alternators and synchronous motors, for example, are tested in exactly the same manner as the fields of d.c. machines, and the same precautions are applicable. Armatures of a.c. commutator motors will respond to the d.c. tests outlined above.

Stator Tests. Stators of alternators, synchronous motors, induction motors, etc., all respond to the general tests outlined below.

Open Circuits. First open the star point, and ascertain on which phase the break occurs, then open up the end connections of the coils on that phase, and test separately.

Short Circuits. A short-circuited coil can be detected by exciting the stator with a voltage say one-half normal, or less for some time. The shorted coil, at the end of the time will be considerably hotter than the remainder, if it does not get hot enough to smoke during the progress of the test.

In the case of alternators it is advisable to remove the rotor during the course of the test, as the transformer action may cause dangerous voltages to be induced in it. If this is not possible, the connections between the field coils should be opened, so as to sectionalize the field, and limit the voltage to that of a single coil. In a case such as this, also, the voltage applied to the stator should be considerably less than half. It should in fact be cut down to a very small value, and the voltage on the fields coil measured, after which it will be seen how much it is safe to raise it.

Another method is to apply a small a.c. voltage to the field circuit, so as to induce voltage in the stator windings by transformer action. Again, the voltage should be kept low, or there is danger of breaking down the stator insulation.

If there is a short-circuited coil on the stator it will get very hot, while the rest of the coils will remain quite cold, since no current is flowing in them. If the field poles of the machine are solid iron, instead of being laminated, this test must not be kept on for long, as the iron itself will get very

hot. This test is an excellent one for locating shorted coils on either the rotor or the stator of induction motors (except the squirrel-cage type).

Another fault which occasionally occurs on old squirrel cage rotors is a partial open circuit due to bad connections between the slot conductors and the end rings. These should

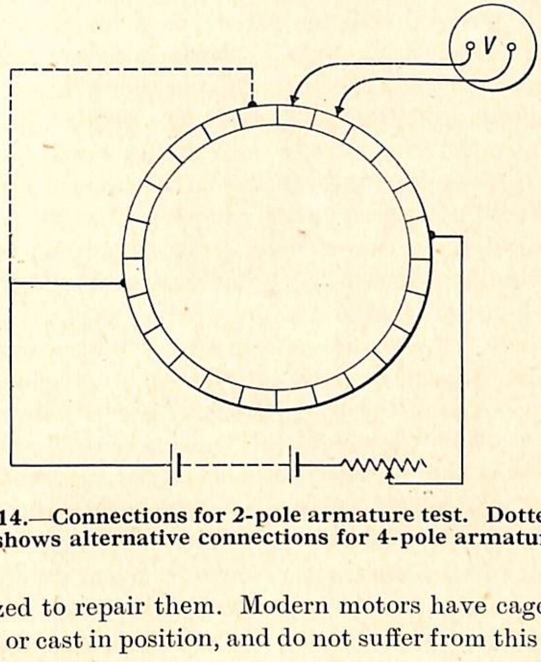

Fig. 14.—Connections for 2-pole armature test. Dotted line shows alternative connections for 4-pole armature

be brazed to repair them. Modern motors have cages either welded or cast in position, and do not suffer from this trouble.

Repairs to Windings

Having located the fault, the problem of its repair next arises. Some repairs are simple, others look simple. The latter are dangerous. It is a simple matter to repair a break in a field coil, and rewind it, particularly on a stationary field, and it is not too difficult to rewind a " mush " or " bunch " winding on a small motor armature. Both these are a question of horse sense, a certain dexterity, and care

taken in obtaining the right size and type of wire, and making an exact duplicate of the previous job. When it comes to former-wound coils, however, a very different state of affairs exists, and it is a choice between returning the machine to the makers, or obtaining a spare coil and fitting it yourself.

A.C. stators are comparatively simple, the chief points to watch being that connections are made in the same direction as before, and that there are no reversed coils. (If extensive dismantling is carried out, label the coil ends.) D.C. armatures are, however, a different proposition.

With the best intentions in the world, it would be useless to try to give any worth-while instructions on the rewinding of machines in the space of this chapter. Winding is one of the most highly-skilled operations in the trade, and can only be really learned by bitter experience. My frank advice to all readers would be summed up as :—

If the winding is on an armature, or if it is on a machine of any size, has closed slots, or is for high voltage, leave it either to a specialist, or to the manufacturer of the machine. In other words, " when in doubt, leave it alone."

If the repair is a simple one, and you are confident of your ability, your golden rule is to put back everything as it was before. No manufacturer does things just for fun. Every bit of insulation is put there for some very definite purpose, even the small squares tucked under the corners of coils, and the wrapping under the binding wires. Don't use brute force to get oversize coils into slots, or cut through the old binding wires with a chisel.

CHAPTER IV

BATTERIES

THE Leclanche cell is probably the only primary cell in general use for bells, buzzers, etc., on account of the small amount of attention required over long periods. Maintenance is limited to occasional inspection, renewal of exhausted zinc rods, and topping-up of the electrolyte with clean water. If the solution is very dirty, or has evaporated, and the salt has crept over the top of the jar and porous pot, it is as well to empty the cell, wash off all deposited salts, and refill with fresh solution, using 3 oz. of sal-ammoniac to 1 pint of water.

A smear of vaseline on the terminal of the carbon will prevent corrosion, which sometimes results in the scrapping of an otherwise good unit, due to the snapping-off of the terminal, and the consequent difficulty of making a good connection. If this should occur, and a spare is not available, drill a 3/16 in. hole in the carbon, place a stout flexible lead therein, and pack hard with tinfoil ; this will make a reasonably good connection which will last a considerable time. (Incidentally, this method can also be used to fix a pigtail on a broken carbon brush.)

Secondary (Accumulators)

LEAD-ACID. The first principle of successful accumulator operation is the importance of correct charge and discharge rates. Modern accumulators will stand a great deal more misuse than their predecessors of a couple of decades ago, but even so, if long life and trouble-free service are to be obtained, the maker's recommendations regarding charge and discharge rates must be adhered to.

Idle Batteries. It is a great mistake to visualize a lead-acid battery as a kind of balloon which can be blown up when convenient, or left deflated when not required, and misuse of this kind costs a lot of money in a comparatively short time. To leave a battery in the discharged state is to invite sulphation troubles which will, at best, cut down the discharge rate, due to increased internal resistance. It will also reduce the actual ampere-hour capacity, due to the replacement of active material by an insoluble salt. At the worst it will cause rapid disintegration of the plates.

A battery cannot be left indefinitely, even if fully charged, as it will gradually lose its charge, and be attacked in the same manner. To keep it in good condition, a battery should be worked regularly and intelligently, being neither overcharged consistently, nor run down to the last trickle of current which it is possible to extract from it. If a battery *must* be left idle, it will require a boosting charge, at the very least every two to three weeks. If it is at all possible, however, keep it working, even if it means a once-a-week discharge through a water resistance, and subsequent charging. A new battery must *never* be left idle.

Overcharging. This should not be confused with an extended charge, which consists of an extra charge, at a reduced rate, for say one hour after the battery has shown itself fully charged. A periodical charge of this nature (say once in every five or six charges) is of great value in keeping a battery in good condition. Habitual overcharging, however, is a fruitful source of trouble, and if persisted in, will cause the plates to shed active material, and may even cause buckling.

Undercharging. This is even worse than overcharging, and will lead in time to sulphation, and its attendant troubles.

Electrolyte. One of the first items to consider, is the quality of the acid used in the cells. It must be purchased as "accumulator acid," and must be diluted with distilled

water. Acid or water containing any impurities will ruin the best battery in a very short time.

Specific Gravity. The specific gravity of a substance, an expression which bothers some people because it sounds so complicated, is actually nothing more than its relative density, as compared with water. Thus if it is said that accumulator acid should be 1.185 (often called "eleven

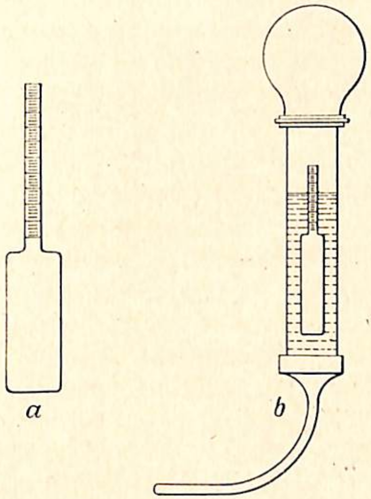

Fig. 15.—Hydrometers. (*a*) **floating type for open cells ;** (*b*) **with bulb and tube for closed cells**

eighty-five"), it means that say a cubic inch of the acid would weigh 1.185 times as much as a cubic inch of water.

Specific gravity is read by means of a hydrometer, usually consisting of a weighted glass tube, which is floated in the acid. The heavier the acid, the higher the hydrometer will float. A scale is engraved on the neck, so that the height can be measured at the level of the surface of the liquid, and is marked directly in specific gravity.

In open-top cells, the hydrometer is placed directly in the acid, for closed cells, it is enclosed in a glass tube, fitted with

a rubber bulb and tube, by which some of the acid in the cell can be sucked up to float the hydrometer in the tube (fig. 15). Some hydrometers have three balls of different weights, which float at different densities of the acid.

It is frequently stated that "the specific gravity of the acid should be 1.220 when charged, and 1.160 when discharged." These figures should be accepted with caution. It is perfectly true that the specific gravity of the acid gives a most valuable indication of the state of charge, *when the upper and lower limits are known.* To lay down hard and fast rules, however, and to imagine that a definite figure can be given for an unknown battery, is rather like measuring the diameter of a hole with a rubber yardstick. In the first place, manufacturers do not always recommend the same s.g. for the acid with which the battery is filled, and the variation of s.g. between charge and discharge is not the same for all batteries. It is, however, true that the s.g. is an approximate indication of the state of any battery, and a remarkably accurate one in the case of a battery whose variation is known. For example, if a battery were known to have s.g. 1.220 at full charge, and 1.160 at discharge, the range would be 1.220-1.160 = .060 (commonly called "sixty degrees") so that a hydrometer reading of 1.190 would indicate a drop of .030 (thirty degrees) from the fully-charged state, thus indicating about half charge.

Variation of S.G. with Temperature. A hydrometer reading will vary with temperature, since the density varies with expansion. Assuming that normal temperature is taken as 60° F., hydrometer readings must be corrected by adding .001 to the reading for every $2\frac{1}{2}$° F. that the temperature of the acid is above 60° F., and subtracting similar amounts when the temperature is below normal.

Voltage of Cells. Variation of the voltage of a cell is another indication of its condition, providing that the cell is actually charging or discharging—the open-circuit voltage is meaningless. Actual values with the cell charging or dis-

charging normally will be about 2.75 volts at the end of charging, and 1.85 at the end of discharge, these varying with the current passing.

Routine Inspection. Batteries should be regularly inspected and records kept of the condition of each cell. These records should show each charge, length and current, the specific gravity and temperature of the acid, and a reading taken with a cell-testing voltmeter on each cell. Notes should also be made on such matters as the appearance of each cell, if other than normal, and a record of such matters as cleaning out sediment, topping-up etc. These records will be found extremely valuable in showing up any deterioration of individual cells, and will allow steps to be taken to remedy any trouble in the initial stages before any damage is done.

Topping-Up. The electrolyte should be kept at least $\frac{1}{2}$ in. above the top of the plates. As it is only the water which evaporates, only water (distilled, of course) should be added, to bring up the level to normal. Topping-up should be carried out when the electrolyte is at its weakest, i.e. before charging, and the water should, if possible be added through a tube or funnel, as deep down as possible, in order to ensure good mixing.

Adding Acid. Theoretically, it should never be necessary to add acid. In practice, splashing or spraying occurs, and this, together with other causes, will gradually weaken the electrolyte, due to the replenishment of all losses with water. If it is certain that the s.g. is low through this cause, acid may be added to bring the strength up to normal. If, however, the s.g. is low due to partial sulphation, or general poor condition, it will only aggravate the trouble to add acid. When there is the slightest doubt, consult the makers.

Sediment. Any cell releases a certain amount of the active material from the plates as a fine sediment or sludge, which collects in the bottom of the container. This should not be allowed to pile up until it touches the plates, or

internal short circuits will be formed. Push the sediment down with a glass rod having a right angle bend near one end, like a miniature walking stick. If it is really excessive, clean out the cell. This is best accomplished by transferring the plates, when fully charged, to a clean container filled with acid of the correct strength. If this is not possible, owing to the size of the cells, or burnt-in lugs, it is possible, with a little ingenuity, to syphon off the acid, wash out with water (syphoning it from the bottom of the cell, complete with sediment), and re-fill with acid.

Portable Cells. The remarks above apply equally to portable cells, but one or two additional complications may arise. For instance, batteries in celluloid containers require special care. The temperature should not be allowed to get too high or the case will soften, and may be attacked by the acid. It is also as well to replace the electrolyte about once a year.

The maintenance of a number of portable batteries of varying types and sizes is much more troublesome than that of a large stationary battery, on account of the number of different charging rates, and the fact that they may arrive for charging at different times. In such circumstances the constant potential charging system is frequently adopted. In this method, the battery is merely connected across a source of constant voltage, of value appropriate to the final charged voltage (say 2.5 volts per cell), and allowed to make its own charging rate, which will be large at first, and gradually tail off as the back E.M.F. rises. This method should be used with discretion, however, in the case of a cell which is very badly " down " or the charging rate will be excessive. A limiting resistance should be used for the first hour or so, until the cell is in fit condition to withstand the full charging voltage.

Troubles with Lead-Acid Batteries

Sulphation. The cause of sulphation has already been

discussed under the heading of idle batteries. The remedy is a long charge at a low rate, say half normal, until gassing commences, when the charging rate is still further reduced to about one-quarter normal. When gassing re-commences, switch off, leave for an hour, then switch on again, until the cell gasses once more. Repeat this until gassing begins again the moment the current is switched on. In really bad cases of sulphation, reduce the s.g. of the acid to about 1.05 before commencing the charge.

Weak Cells. A cell which is not up to the standard of the rest of the battery, but does not show definite signs of sulphation, can often be cured by cutting out of circuit on discharge, and reconnecting on charge, two or three times in succession. If this has no effect, a very careful examination should be made, to determine the cause of the trouble.

Buckled Plates. Buckling may arise from sulphation or general misuse, such as gross over- or under-charging. Stationary batteries with soft plates can sometimes be straightened without breakage by heavy pressure between hardwood boards (preferably teak). If the plates seem brittle, try a long charge at a low rate, to soften them. Car accumulators, and similar batteries, which have thin plates of a hard alloy, can seldom be satisfactorily straightened.

Internal Shorts. An internal short, unless the plates are actually touching, or a separator has broken down, is usually due to a spongy growth between plates, round the edges of the separator, or to excessive sediment. The cure for either fault is obvious.

Container Breakage. The negative plates should not be allowed to dry, but should be placed in distilled water, while a new container is obtained.

Miscellaneous Points to Remember

A properly charged battery has a closed circuit voltage of about 2.75 volts per cell, and gasses freely from *both* plates, until the acid has almost a milky appearance. The

positive plate should be dark chocolate, and the negative clear blue-grey. Both plates should be clean, and not "patchy" or dirty.

Do not use naked lights in a battery room, when the cells are gassing; have the room well ventilated, but not so draughty that it causes excessive evaporation; use clean jugs for topping-up; have washing soda or caustic soda handy to neutralize acid splashes; don't forget the virtues of vaseline for preventing corrosion of copper and brass terminals; use anti-sulphuric enamel for all paintwork; and remember to keep regular records.

ALKALI CELLS. The nickel-iron and nickel-cadmium cells using an alkaline electrolyte compensate for their additional first cost and greater bulk, by requiring very little maintenance. They require the electrolyte level checking periodically, and topping up when required. The s.g. should also be checked occasionally. Unlike the lead cell, this does not vary with the state of charge. They are not affected by being allowed to stand discharged, or charging in excess of the normal rate but the electrolyte will require renewal every two years.

CURRENT RATINGS, ETC., FOR FLEXIBLE CORDS.

Extracted from the 1939 Regulations (by permission of the Institution of Electrical Engineers).

Nominal area sq. in.	Stranding	Current rating, 2, 3, or 4 core	Maximum weight which may be supported by a twin cord
.0006	14/.0076	2 amp.	3 lb.
.001	23/.0076	3 ,,	5 ,,
.0017	40/.0076	5 ,,	10 ,,
.003	70/.0076	10 ,,	10 ,,
.0048	110/.0076	15 ,,	10 ,,
.007	162/.0076	20 ,,	10 ,,

CHAPTER V

SWITCH AND CONTROL GEAR—1

As the maintenance of contact surfaces forms the major part of switchgear maintenance, it will be of advantage to study them in some detail. They may be divided into two classes : surface and line.

Surface Contacts

These depend for efficient operation upon large flat areas in intimate contact, usually under spring pressure. The slightest irregularity in either surface means that the contact cannot be intimate ; it is therefore important that perfect flatness is obtained. On large and important contacts, grinding or bedding-in with an abrasive is frequently resorted to, as described later under lever switches.

Test for Area of Contact

The actual contact area, i.e. the part which does useful work, is found by the marking method, familiar to every fitter. The two surfaces are smeared *lightly* with a marking paste, either red lead or Prussian blue mixed with oil, and are then put into their working position, and separated once more. The areas making proper contact will show up. Another method, quicker but not so accurate, is to squeeze a piece of thin white paper between the contacts, and examine the resultant markings.

Line Contacts

It has been recognised for a long time that the pressure between contact surfaces is more important than the

actual contact area. Since with large areas, the pressure per unit area remains low, even with heavy pressures, the trend of development has been towards cutting down the areas. To cut a long story short, it has been proved that a *line* contact under heavy pressure is extremely efficient. Line contacts are formed when two curved surfaces touch, or a curved surface touches a flat one, and in both these forms they are largely used in circuit breakers, contactors, and the like.

In the contactor type of contact, the line principle has another advantage, in that it is possible to allow the contact surfaces to roll over one another, on closing. This results in the final contact being made at a different portion of the surface from the point at which the two surfaces first touch, so that initial burning on " making " is excluded from the final contact, which takes place on an unburned portion of the contact (fig. 16).

The line contact is amply justified in both theory and practice. Do not, therefore, imagine that you will increase the capacity of such a contact by filing a flat upon it with the object of increasing the area of contact : such a course will have the opposite effect. Line contacts are line contacts, and surfaces are surfaces, and no light-hearted attempts should be made to convert one into the other. The designer of the gear had excellent reasons for selecting the one or the other, and his decision should be respected.

Cleanliness of Contacts

The oxide film which forms on copper contacts greatly reduces their conductivity, and causes overheating. This, in turn, will cause increased oxidation, and a vicious circle is formed. Clean contacts are, therefore, essential, and the periodical cleaning will form an important part of your job. Use glasspaper rather than emery, and remember the ever-helpful smear of vaseline for all contacts which are not oil-immersed, to assist in preventing oxidation.

Silver Contacts

Silver is freely used nowadays as a contact material; it is an even better conductor than copper, and does not deteriorate in the same way. It is usually applied either as a silver plating of the parts in question, or as solid silver sheets sweated to the copper. When overhauling apparatus with

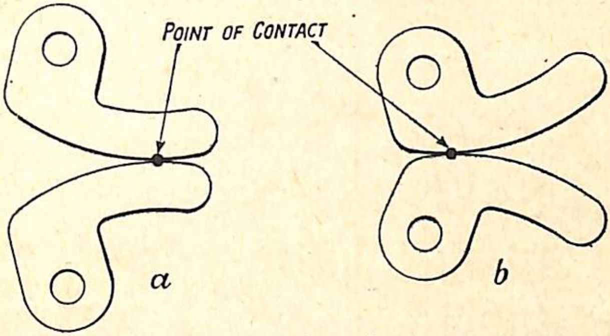

Fig. 16.—Showing rolling action of contactor type contact. (*a*) just making or separating; (*b*) normal "closed" position

silver-plated contacts, remember that the plating is only a few mils thick, and resist the temptation to clean it up with abrasive, even though it may look dirty. The discoloration will not affect its contact resistance, and the use of abrasive will merely remove the silver and expose the copper, thus defeating the object of the plating, and making matters ten times worse.

Silver contacts are never used to make or break circuits, except on relays. For all heavy work, such as switchgear, they are always protected with arcing contacts, which make first, and break last. Look to these well, for if allowed to get into bad condition, they will fail in their duty, and allow the main contacts to be burned.

Types of Contacts

The contacts fitted to air circuit breakers are usually of the brush type, consisting of a large number of thin strips or

laminations, bunched together, and bent into a bridge shape, which bridges between two fixed blocks, so that contact is made between the surface of the blocks, and the ends of the bunch of laminations (fig. 17). This type may be regarded either as a multi-line contact or a flexible surface contact.

It is usually protected with auxiliary contacts of carbon or metal, and sometimes has magnetic blow-outs. Air breakers

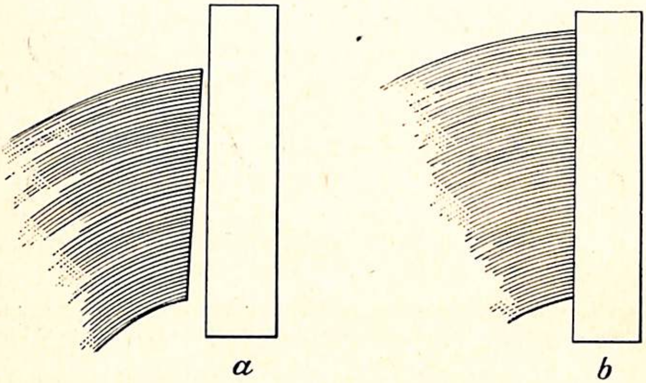

Fig. 17.—Brush contact. (*a*) **before making, showing angle of rake ;** (*b*) **after spreading**

are also found with line pressure contacts, either copper or silver.

Brush type contacts are occasionally to be found on oil circuit breakers, but the majority have an inverted " V " moving crossbar. The stationary contacts consist of a number of fingers, flexible and spring-loaded, arranged at an angle to suit the crossbar, so that it can be forced up into the space between the two rows of fingers, with a wiping action. Main contacts may be either copper or silver, arcing contacts are copper, and both main and arcing contacts may be either surface or line type (fig. 18).

In order to prevent the fingers being weak and " floppy " as they would be if weak springs were used, restraining devices are used on circuit breakers of good design, so that

heavy spring pressure can be applied without the fingers closing together, and preventing the entry of the crossbar.

Oil circuit breakers are also fitted with contactor type contacts, having a rolling action, as previously described.

Following the preliminary remarks on contacts let us now turn our attention to actual maintenance work on various pieces of apparatus.

Lever or Knife Switches

The only maintenance these should require is cleaning, if oxidised. If the switch overheats, bed in the contacts, by smearing a fine paste of powdered pumice and oil over the contact surfaces, and working them backwards and forwards until good contact is obtained. Carefully clean away the grinding paste afterwards, or you will find yourself in the same predicament as a friend of mine, who used metal polish and only *thought* he had cleaned it off again. Located

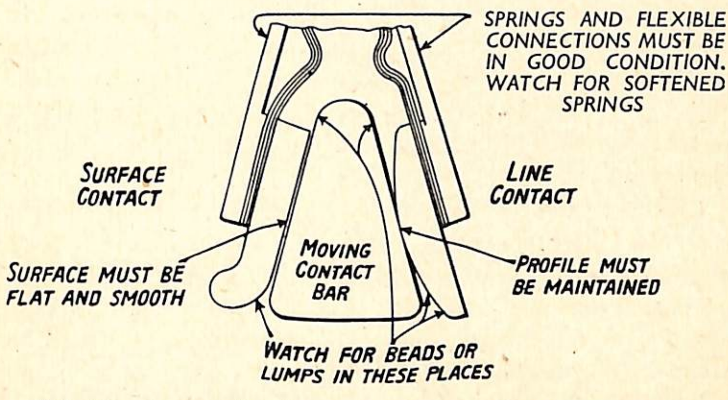

Fig. 18.—Composite diagram of surface and line contacts for oil circuit breakers

in an important substation, as the evening peak load came on, he realized that he had not done so, and finished the shift with the table for standing on a chair by the board to keep the

switch from melting. The moral should not require diagrams to make it clear.

Emery, or any other hard abrasive which tends to embed itself in the copper, should not be used.

Replace damaged springs on flicker blades, or quick-break mechanism. Where the contacts are badly burned, file off all beads, and jagged edges, and re-bed. Keep the bolt at the hinge contact tight, and if a spring washer is used, replace it if it becomes softened through any cause.

Air Circuit Breakers

These should only require occasional attention to the arcing contacts. The main contacts, usually of the brush pattern, should not require attention. If by some mischance they should be burned or otherwise seriously damaged, they should be replaced. It is practically impossible to repair a damaged brush, although slight burning can be remedied by removing the brush and filing the ends. These should be filed on the slope, so that when pressed on the block the outer strips of the brush make contact first, otherwise when the brush spreads, the outer strips will not make contact at all (fig. 17). The mechanism will require adjustment, if any amount has been removed from the brush, to maintain the original pressure.

Carbon arcing tips should not require attention throughout their working life, except to adjust for position as they burn away. Intermediate contacts, if fitted, should be trimmed up if they become pitted. It is most important to have all arcing contacts in good condition, and correctly timed to make before, and break after, the main contacts, or these will be burned.

In the case of breakers which very seldom operate, trip by hand every three months or so, to ensure that the mechanism is not sticking or rusty, and examine the automatic trip mechanism, and the reverse trip, if fitted. A *drop* of oil or a smear of grease on mechanism pins, if these show signs

of rusting will prove a good insurance against future trouble. Time lags are dealt with later.

Battery Cut-outs

See that these are clean, that the mercury in the cups is at the correct level and has not deteriorated to a pinch of slag or dross, and that the pivot pins are not sticking.

Fuses

One of the chief troubles occurring on rewirable fuses using copper wire is the oxidation of the wire, if run at a high current density, causing a reduction in area, and consequent false blowing, i.e. blowing at a current below its rated value. If, therefore, a fuse is consistently run at a normal load of about two-thirds of its fusing current, you must be prepared to replace the wire periodically, or put up with false blowing. It is advantageous to use either alloy wire, or pure tin for the smaller circuits, to save this trouble. Alloy wire for the larger circuits suffers from the disadvantage that there is a much greater mass of metal for the same carrying capacity, and hence a greater " splash," when blowing.

Whatever type of wire is used, whether tin, copper, or tin-lead alloy, there are certain fundamental principles of fuse maintenance which must be attended to. These are :

1. Keep all contact surfaces clean and in good condition. If springs are fitted and are found to have softened, replace them, and investigate the conditions under which the fuse is operating, to ensure that the maximum rating is not being exceeded. Any given fuse handle has a normal rating assigned by the manufacturers, who are meeting a keen competition, and cannot afford to give material away. The old idea that anything should be twice as good as it says it is, is rapidly dying, and a fuse marked " 15 amps 250 volts," is meant to be wired with any size of wire up to a normal capacity of 15 amps. Do not, therefore, imagine that by inserting a 20 amp wire, the fuse is good for 20 amps. It may be, but you

have no right to expect it to do anything of the sort. No sane person complains of the poor quality of a pint pot which will not hold a quart, but many complain bitterly because apparatus designed for a competitive market has not a large margin over and above its rating.

2. When replacing a blown fuse, use the correct size and quality of wire, and also see that it is inserted as the designer intended it to be. If the handle is arranged so that the wire passes through an asbestos tube, or under a damper pad, *wire it up that way*. These devices are put there for a very definite purpose, to extinguish the arc at the earliest possible moment, and if the wire is merely looped around the terminals in the shortest possible path, as so often happens, the arc may hang on and cause a violent explosion due to the formation of gas.

3. Lead the wire under the washer of the clamping screw, and clamp sufficiently tightly to give good contact. Do not clamp too tightly in the case of alloy wire, or you will squeeze it flat and cause a thin spot, which may cause false blowing. In addition it may cause blowing just where it is not intended to, at the terminal instead of in the middle of the wire, thus burning the fixing screw. Don't lose patience with a very thin wire on a very small fuse handle, and merely wrap the wire round the screw and tighten up. The wire will be cut through by the screw thread, and you will only have to do the job all over again.

Cartridge Fuses

With these, the only maintenance possible is the cleaning of the contacts, and the replacement of blown fuses. You may find it an advantage to use "indicating type" cartridges, to save time in identifying a blown fuse, where a number are installed together.

If a cartridge fuse blows, and a spare is not immediately available, don't wrap a few strands of wire around the clips, and leave it. If you *know* the fault is cleared, and will not

recur, and every second is precious, and contrary to all advice you *will* do it, don't forget to replace it at the earliest possible moment, or when it does blow it may give an unsolicited testimonial to the superiority of the cartidge fuse. Besides, there is no need for it. If in every fuse cabinet, or on every fuse board, where there are a number of cartridge fuses, there is not a set of clips holding spare fuses—there ought to be.

Oil Circuit Breakers

Oil circuit breaker maintenance falls under two headings ; routine and emergency. The first consists of regular inspection at fixed periods, the second, immediate inspection, and if necessary, repair, after the occurrence of a heavy fault. An oil circuit breaker, unlike a machine, does no useful work while all is well. For perhaps 99 per cent. of its working life, it is merely a link in the circuit, and providing it carries its normal load without overheating, no more is asked of it. When an emergency arises, however, its useful function begins and, in a few hundredths of a second, it is called upon to undergo, without failure, greater destructive forces than fall to the lot of most apparatus in a life-time of service. In this it may be compared to a standing army in peace and war ; if it is to be fit to act in emergency, it must be maintained during normal times. A circuit breaker may not operate, literally, for years, and it must not be found that when it is called upon its mechanism is rusted solid or its tank is filled with sludge. (Cases are on record where circuit breakers have been found with tanks completely empty, when it *did* occur to someone to take a look at them.)

Routine Maintenance

The tank of an oil circuit breaker should be removed every 3-4 months on normal duty, or as often as once per month when a breaker is operating on heavy duty, and both oil and contacts examined.

Contacts

These should be in good condition. If there is any burning or excessive roughness, they should be trimmed up with a fine file or glasspaper, according to the extent of the damage. Surface contacts should give contact over at least 80 per cent. of their area, and it should not be possible to insert a .002 in. feeler between fixed and moving contacts in the closed position. A little more latitude may be allowed to arcing contacts, but no excessive roughness or beading should be allowed. If line contacts are filed, it is essential that the profile of the contact is not altered (fig. 18). If the surfaces are too badly burned to be dressed, they should be scrapped, and replaced by new ones. Make sure, when fitting any spare contacts, especially moving ones, that all screws and nuts are securely locked, they will have to withstand considerable jarring and vibration, and loose parts inside an oil circuit breaker may have the most disastrous results.

The same remarks regarding cleaning and dressing apply to explosion pot contacts, which should also have the insulating parts examined for tracking or burning.

Oil

The condition of the oil, particularly in a high-voltage breaker, is of extreme importance. It must neither be wet nor dirty. Both these terms require explanation. Oil requires only a minute amount of water, particularly when combined with carbonised matter, to be useless. By " water " is not meant amounts measured by the pint, but amounts which might be absorbed from the atmosphere by leaving a drum in a moist atmosphere for a few hours, without the bung in position, and then using it to store oil in.

Oil may have changed colour without being actually dirty. It will usually be found to be much darker than it was when first put in, but if it is clear it will probably be satisfactory. If it contains actual sediment, or floating specks

of carbon, it will have to be cleaned by filtering through *dry* blotting paper, in a dry atmosphere. Many different types of oil treating plant for various outputs are manufactured, and if there is any quantity of oil to be dealt with these represent the only practicable way of handling the job. If the quantities of oil are small and infrequent, it will probably be found cheaper to throw the old oil away, but careful calculations should be made first, to determine the economics of the situation.

The only real criterion of the condition of oil is the dielectric strength as determined by the breakdown test. Portable oil testing sets are sold for this purpose, consisting of an oil

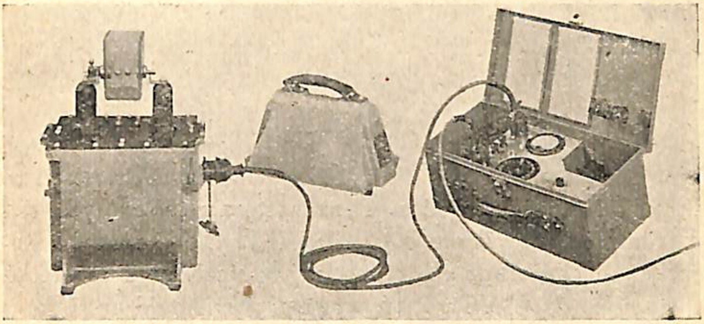

Fig. 19.—Portable oil-testing set, arranged for test and showing test vessel and spherical electrodes

vessel with electrodes, and a small H.T. transformer, with regulator and voltmeter.

The standard test, as laid down in British Standard Specification No. 148, is between $\frac{1}{2}$ in. spheres, 0.15 in. apart, and breakdown should be not less than 22 kV under these conditions.

If it is inconvenient or impossible to make this test, a rough indication as to moisture content is given by boiling a small quantity in a test-tube, or by plunging a hot poker into it. If the oil gives off a distinct crackling sound, it is

wet. Make quite sure that the tube or other receptacle is clean and dry.

Insulating oil is bought to a British Standard Specification (148), and is graded either class " A " or class " B." Class " A " will stand a higher temperature without sludging, and is therefore sometimes used for heavy current breakers, or for use in the tropics, and is the usual grade for transformers Each grade is subdivided into three subgrades, A_{10}, A_{20}, A_{30}, B_{10}, B_{20}, B_{30}, the figures indicating the number of degrees below 0° C. at which the oil solidifies. In England the " 30 " grade is most commonly used, while for warmer climates the other two might be more suitable. Switchgear uses, as a general rule, Class B_{30}.

MIXING OF OIL. Haphazard mixing of oils is not permissible. Even oils to the same BSS grade, from two different manufacturers must not be mixed without a definite O.K. from one or the other. If you do not know the original supplier of the oil, consult the switchgear manufacturer, giving full particulars of the oil with which it is proposed to mix the oil supplied by him. The reasons are too complicated to go into here, and are concerned with the chemical composition of the crude oils, the geographical location of the wells and so on. Suffice it to say that you should not take a chance.

When replacing old oil with fresh, do not forget to wash out the tank and contacts, etc., with a little clean dry oil, otherwise you will just transfer some of the moisture from the old oil to the new.

When sampling oil, take it from the bottom of the tank, where most of the moisture collects. If there is no tap on the tank, use a " thief." This is a clean tube which is plunged into the oil, the upper end being closed with the finger, when inserting and withdrawing it.

Store oil drums in a dry place, with bung downwards, and do not open on a damp day. Be scrupulously careful not to use dirty vessels.

CHAPTER VI

SWITCH AND CONTROL GEAR—2

Other Parts of Circuit Rreakers

Clean all insulators, if they are dirty or dusty. External insulators, if the dirt does not come off easily, may be cleaned with a weak solution of ammonia. (*N.B.*—This applies only to porcelain.) Never use anything on internal insulators, but a little clean oil; water will be fatal, after the precautions you have taken to obtain dry oil. Never use cotton cloths or swabs inside a circuit breaker, the fluff and fibres will collect in the oil to form " chains " leading to breakdown. Use a chamois leather.

Check the operating mechanism and make sure that there is no rusting or sticking, see that the plungers of all overload and low voltage devices move freely, and are properly adjusted. Inspect all buffer springs, dashpots, etc., on the circuit breaker. See that all terminal nuts on main connections are tight and locked.

If electrically operated, check operation under power, see that closing and tripping take place without any hesitation, and that ample power is provided. A breaker which will only just close on no-load will suffer severe damage if it is ever closed on to a fault. Check all secondary wiring, for cleanliness and tightness of terminals, paying particular attention to tripping circuits. Inspect all fuses, and the power supply for trip circuits, if shunt trips are fitted.

Time lag devices, if fitted, may be either electrical or mechanical. If relays are used, they may be tested electrically, but it is inadvisable to attempt adjustment of delicate relay mechanisms, other than changing settings, unless you

have considerable experience of this work. If the time lags are simple fuses, shunted across the trip coils, examine them carefully for signs of deterioration, and clean the contacts if necessary. Oil dashpot time lags should be examined for dirt and grit, which may cause sticking. See also that any non-return valves are functioning properly, and are not propped open with a small piece of grit. Clockwork timelags, if damaged due to misuse should preferably be repaired by the makers, unless you are used to delicate work, they do not respond well to the " strong arm " type of repairs.

Replacing Tank

When replacing the circuit breaker tank after maintenance, look to the following :—

1. The tank is on the right way round.
2. The lining or phase barriers are not distorted or damaged.
3. The gasket or packing round the joint is in place and undamaged, unless a metal-to-metal joint is used.
4. If the tank fits into a groove or spigot make sure that it *does* fit, and is not merely pressed against the edge.
5. Have all tank bolts as tight as you possibly can. A great deal may depend on this. Do not, however, go to ridiculous lengths such as using gas-pipe extensions to the spanners, or you *may* break the lugs off the tank.

In conclusion, never forget that a circuit breaker is your first and last line of defence, and that the best British circuit breaker, than which there is nothing finer, may fail if it is neglected, or subjected to makeshift repairs. Follow the maker's instructions regarding detail adjustments with the greatest care.

Oil Circuit Breaker Repairs

Apart from sticking mechanisms, due to neglect or misuse, or burned contacts, the question of repairs does not usually arise. Circuit breakers are robust things, and barring a complete failure, which will cause damage which cannot be

repaired on site, the only trouble is mechanical damage, which has practically to amount to sabotage. If, for example, a solenoid-operated breaker were being operated with the tank removed, and you leave a spanner in its internal economy before pressing the button, then it will certainly need repairs. Except for this sort of thing, the only other repair is the replacement of a broken terminal insulator. Circuit breakers vary greatly in design, and it is not possible to give detailed instructions for renewing insulators, which may be either simple or difficult, according to the method of fixing adopted.

If bolted clamps are used, the question of repair is simple, requiring only common sense, and the ability to line-up the new insulator correctly. If leaded or cemented, however, a factory repair is preferable as the insulators are jig-set during fixing. If this is out of the question, the general procedure (subject to any special instructions issued by the manufacturer), is to assemble the contacts, and terminal stud, in the new insulator and, with the breaker closed, locate it carefully in the correct position, tamping it in place with clay or asbestos string, or both. The tamping should be from underneath the body so that a clear pocket is left for the fixing material, which may be either metallic or a cement (see Chapter IX). If metallic, a lead-antimony alloy of the type metal class, should be used, as this expands slightly on cooling.

The treatment will be generally as described for the renewal of white metal bearings, including the pre-heating of the parts, which should not, of course, be overdone. Do not forget to remove the packing, and make sure that no drops of metal have fallen through into the breaker.

Metallic filling cannot be used for bakelized paper insulators, which must be cemented (see Chapter IX) It is, however, very rare to find a damaged paper insulator, providing reasonable care is taken, and the paper is not scratched.

Routine Maintenance of Switchgear in General

Once again, detailed instructions are impossible, on account of wide variations in design. The one fundamental principle of maintenance: cleanliness—still applies. As with all other forms of gear, dust will form leakage paths, and must be removed. All types of switchgear need regular cleaning, such portions as busbar and spout insulators requiring special attention. Keep a sharp look-out for cracked insulators, which should be replaced at the earliest possible moment.

Isolating switches, or plugs and sockets require attention to ensure that good contact is being made.

The small wiring of secondary circuits should be inspected, and terminals tightened if necessary. Make sure that any plugs and sockets, or link boxes on drawout gear are clean and making proper contact.

Look for any oil or compound leakage, and remedy the trouble. Oil-tight joints should be made with a gasket of a good quality oil-proof material as sold for the purpose; the paper-cum-gold-size joints as used on car crank cases are useless. When bolting-up a joint, screw up the nuts a little at a time in turn, do not run each one down tight separately.

If the compound is leaking it is a sign that something is overheating, and investigation should be made before any trouble develops. A putty for sealing compound leaks is given in Chapter IX.

Inspect all earthing connections, and check all interlocks; if mechanical, see that there is no sticking or rusting.

In cellular, cubicle, or truck switchgear, be very certain that no holes exist that will admit vermin. Many a mouse has shut down the supply to an entire town, before now. Pay particular attention to the part where cables enter the gear from trenches, and cover the hole with two plates, each having a semicircular piece cut out of one edge, so that the two form a hole which encircles the cable, the space being filled with a split wood bush.

Rheostats, Starters, etc.

Rheostats of the slider type require little beyond occasional cleaning of their contact surfaces, and a smear of vaseline on the slide bar, and operating mechanism (if fitted). Those of the type with a dial switch, and resistance grids or tubes, require blowing out occasionally, to prevent dust which is carried in by the warm air rising, choking up the ventilation apertures, and forming a film over the radiating surfaces.

If a resistance persistently overheats, it may be worth

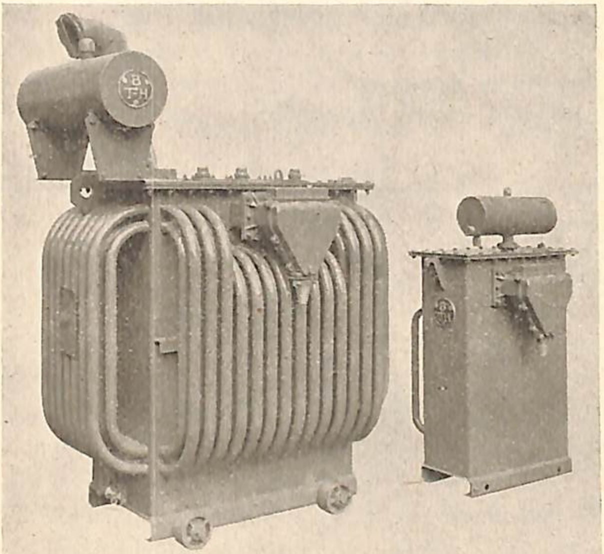

Fig. 20.—Typical distribution transformers with conservators (400 and 45 kVA)

while changing its position, if it is possible, to some other location where better air circulation is obtained.

Do not forget that resistances are intended to get hot, some running as high as 300°C., and that as long as they do not get hot enough to damage either themselves or any adjacent apparatus, no particular harm will result.

Many rheostats are graded, i.e., the resistance is applied

in unequal steps, the higher resistance steps being suitable for smaller currents than the lower steps, which are intended to be cut out last. In such cases, where 3-terminal rheostats are concerned, make sure that the connection is made to the right end of the winding. This is sometimes the cause of coarse regulation, high temperature, and burn-outs on shunt field regulators.

Insulation troubles occur sometimes on rheostats, notably the carbon pile type, where a number of carbon plates are supported between steel rods covered with porcelain sleeves. Damage to the porcelain usually results in earths and shorts, and the porcelains must be replaced. Fibre tubes may be used as a makeshift, but will very soon burn away, and a few mica washers, to replace the damaged section, will be better.

Burn-outs occasionally occur on wire-wound tubes and can be very troublesome. In the first place, the wire is usually wound under some tension, and when it parts, frequently unwraps and touches adjacent tubes causing shorts and fireworks. As the wire is usually insulated with a film of oxide, jointing is troublesome. The wire *should* be welded, but this is very seldom possible, and soldering is out of the question on account of the temperature. Perhaps the best repair is made with a nut and bolt or a pinch-screw connector. In the case of rheostats which have the elements embedded in vitreous enamel, or fireclay composition, the only possible repair is to short-circuit the switch contact studs on either side of the break with a piece of 16 s.w.g. wire, soldered round the edge of the studs, so as to clear the moving contact arm. This will, of course, reduce the resistance value, but may save the scrapping of an otherwise serviceable unit.

Faceplate Starters

The commoner troubles, arising from neglect or misuse, are as follows :—

1. Handle not returning properly to the off position, due to a broken or weak spring, which should be replaced. If the residual magnetism of the hold-on coil is too much for the spring, try a stronger spring, or a piece of copper foil over the magnet pole-piece, or a tiny brass pin inserted in the pole-piece.

2. Handle failing to hold on, due to the coil being externally short-circuited (overload release sticking) or internally shorted (faults between turns), in which case it should be rewound. Rewinding is necessary if the starter was not designed for that particular motor, and the field current is too low. In this case rewind with more turns of a smaller wire, using your own intelligence as to the size selected. (Don't forget that the area of a wire varies as the *square* of its diameter. It's elementary, but many a good man has tripped up on it.)

3. Uncertain or intermittent contact on the starter, due to burned or dirty contacts. This should be promptly attended to, as the trouble is cumulative, and has a bad effect on the motor. If the circuit is broken long enough to allow the speed to fall, the sudden application of voltage on the next step may cause it to flash-over.

As with all other apparatus, cleanliness is most important. If the overload contacts are allowed to get dirty, or the pivots rusty, it may not operate, and the motor may be damaged.

Another trouble which has occurred with poorly designed starters and is not always obvious, is where the starter arm, usually live, with the usual wooden or moulded knob, secured by a metal stud, has made contact with a sheet metal cover. In some cases the cover is not as robust as it might be, considering the places where starters are frequently tucked away, and the rough usage they have to put up with. The resulting earth fault, when the smoke has cleared away, and the starter has been re-conditioned, may be prevented from recurring by shrouding the stud with an

insulating tube, and not by a wrapping of black tape, which will be cut through by the edge of the slot. It should be noted that this trouble is not likely to occur with a modern starter.

Liquid Rheostats

Maintenance of these includes topping-up of electrolyte, and a periodical clean-out, when all corroded parts must be thoroughly scraped and cleaned. Anti-sulphuric enamel, or bituminous paint should be applied wherever corrosion occurs, except the electrodes, which must be renewed. Short-circuiting or interlocking contacts should be cleaned and well vaselined, as must any exposed terminals.

The electrolyte consists of a solution of caustic soda or washing soda in water, the exact proportions varying with the resistance required, but one part in 300 may be tried and if the resistance is too high, the amount of soda may be increased. After the strength reaches 1 in 100, very little decrease in resistance is shown for the addition of extra soda. When adding soda, add it in the form of a strong solution ; never throw dry crystals into the container. Do not forget that the resistance will fall as the temperature rises.

Contactors and Automatic Control Gear

Once again, at the risk of wearisome repetition, comes the same advice—keep your gear clean, and contact surfaces trimmed, and free from beads and pitting. Keep a sharp lookout for any loose bolts or nuts. A contactor is a pretty robust piece of mechanism, but it occasionally happens that an a.c. contactor may hum or buzz sufficiently to loosen screws which hold it together. If this should occur, it will rapidly shake itself to pieces. An a.c. contactor which hums over-much should always be suspect.

D.C. contactors which stick in, due to residual magnetism, may be cured by covering the pole face with a piece of very

thin copper foil to prevent the iron surfaces touching. Make sure, in the case of a contactor which has no springs but is operated by gravity, that it is mounted truly vertical, as this may affect the operation.

Auxiliary contactors, and relays used on automatic control gear, should be periodically examined to ensure that they are not sticking, as in these the working forces are frequently small. Relays of the thermal type occasionally suffer from distortion of the metal strip due to heavy overloads.

Where an automatic starter, for no apparent reason, fails to operate, the only course is to trace methodically through the connections with the diagram, trying it out step-by-step until the faulty link in the chain of operations is revealed. This may be anything from an open-circuited coil to a dirty auxiliary contact. Do not forget the push-button of an automatic starter ; it may be the cause of trouble.

There are two rules to follow carefully in this work. The first is—make sure that all apparatus is dead before you handle it ; the second—make sure before pulling anything to pieces, that a supply is available, and that the trouble is not a blown fuse, or something equally silly. This is another elementary, but sure-fire trick.

Calculation of Temperature Rise

A sufficiently accurate method of computing the rise in temperature of a winding, by measuring the increase in resistance, is to take each 0.4 per cent. rise in resistance as equivalent to 1° C. rise in temperature.

Remember that Rise in °F. is 9/5 of the rise in °C., and that actual temperatures may be converted as follows :—

To convert °C. to °F. .. Multiply by 9/5 and add 32.
To convert °F. to °C. .. Subtract 32 and multiply by 5/9.

CHAPTER VII

TRANSFORMERS

These probably require less attention than any other type of apparatus, and it is no uncommon thing for them to be entirely neglected for many years. This, of course, is quite wrong.

Every three years at least (and every 6-9 months during the first 3-4 years after installation), a transformer should be lifted from its tank, and carefully examined as follows :—

1. Oil. Exactly the same precautions as to dielectric strength, dryness, carbonization, sludging, and mixing should be taken as described under " Oil " in Chapter V, page 58 *et seq.* Transformer oil is usually class A_{30} in this country but this point should be checked with the manufacturers if there is any doubt.

2. Any sludge or dirt present in the tank should be cleaned out, paying particular attention to the cooling tubes.

3. Any sludge or dirt present on the core and coils should be carefully cleaned off, paying particular attention to the ducts in the core through which oil circulates for cooling purposes, which, if choked, will cause hot spots and general overheating.

4. The core should be examined for any traces of burned or damaged laminations, the signs of eddy currents due to broken-down core bolts.

5. All core bolts should be tested for tightness, particularly if the transformer is inclined to hum. Core bolt insulation should be tested for resistance between core and bolt. If any are " down," renew the insulation.

6. Examine windings for weak or burned patches which

may have been caused through faults that afterwards cleared themselves without causing a complete shut-down. Any such places should be re-insulated.

7. Examine all coil supports and connection clamps. Coil supports are usually adjustable to allow for coil shrinkage, and, if there is any looseness, the coil supports and clamps

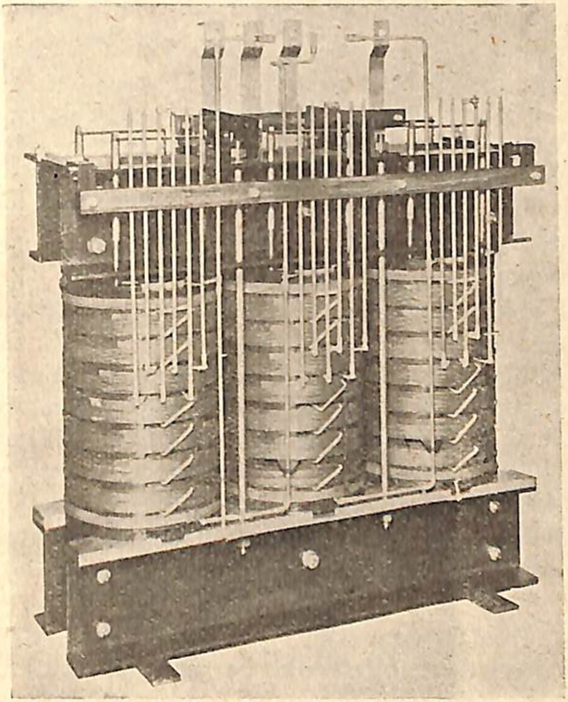

Fig. 21.—400 kVA, 3-phase, 6,600/430 V transformer, showing core and coils

should be adjusted to suit. Movement may have taken place due to short-circuits on the transformer. These windings must be solidly clamped. Pay particular attention to connections from tappings, if these are fitted, and make quite

sure that they are well braced and supported. See that no connection clamps or coil supports are suffering from burning or "tracking" due to intermittent breakdown. If they are, replace them, and look to the coil insulation immediately beneath.

Having attended to the above points, the transformer being clean and dry, may be replaced in its tank, which should be filled with clean dry oil.

The following precautions should be observed when dismantling transformers :—

1. Choose a dry day for operations—particularly in the case of outdoor transformers. "Dry" does not merely mean free from rain, but that the atmosphere should be dry.

2. Be very careful in removing and replacing the transformer that it does not foul the edge of the tank, possibly causing serious damage to the windings.

3. Do not, in any circumstances, leave tools, spanners or nuts lying about on the top of the tank, either with the core out, or with the core in position, and a hand-hole cover off. (This also applies when tap-changing on a transformer which has link boards, instead of a tapping switch.) All nuts and bolts should be removed, and any spanners secured with a lashing of string to a ring-bolt. Watch all loose objects in your pockets, as anything dropped into a transformer is exceedingly difficult to remove, and will cause trouble sooner or later.

External Inspection

A regular inspection should be made of the external condition, and the oil gauge and thermometer read as often as possible. Do not forget that if the gauge shows minimum level when the temperature is high, it will be below that level when the temperature drops. Keep all insulators clean.

Oil Expansion

With the variation in temperature, the oil will vary in volume, and the transformer will breathe air in, depositing

moisture in the oil. There are three methods of preventing this—total sealing of the tank with an expansion diaphragm ; conservators ; and breathers.

Conservators

By the use of this small auxiliary oil tank, mounted above the transformer, to give a pressure head, the tank is always

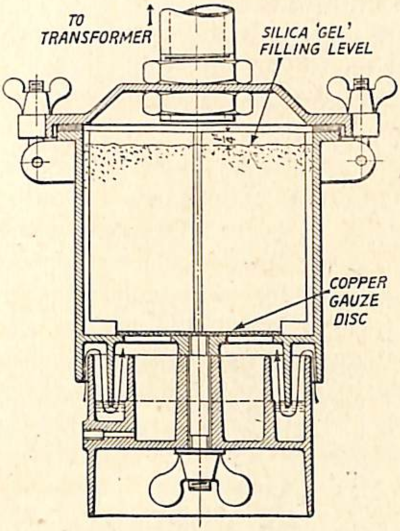

Fig. 22.—Silica gel breather

kept full of oil and air is not admitted to the tank. A transformer so fitted will need particular care with the oil-tight joints, and when dismantling it will be necessary to run off a quantity of oil rather in excess of the conservator capacity, before breaking the tank joint, when dismantling.

Breathers

By this method, the air is allowed to pass into the tank, but is dried in its passage through the breather, where it is drawn through a winding passage, over a drying agent such

as calcium chloride or silica gel (jelly). At regular intervals (depending upon air humidity and maker's instructions), the drying material having absorbed its quota of moisture, must itself be dried. This is done either immediately, and the material replaced at once, or a fresh charge is substituted while the first is being dried.

Emergency Conditions

A transformer must be taken out of service and opened up immediately any of the following conditions occur :—

1. Serious overheating (oil temperature exceeding the BSS rise of 50° C. above air temperature, by any marked amount). Before opening up, however, be very sure that the trouble is not due to external circumstances. Check the loading and make sure that there is neither a straight overload, or heavy wattless circulating currents due to the transformer being incorrectly paralleled with others. By incorrectly, is meant that it is operating on, say, the wrong tapping, as sometimes the tap is changed on one transformer of a bank and not the others. In the case of a new transformer being put into service, it may be wrongly connected ; a star-star transformer will not parallel with a star-delta, for example. Also the impedances may differ, so that they do not share the load. If in doubt, consult the maker.

2. " Spitting " noises coming from the tank, indicating sparking or intermittent arcing under the coil. Prompt action may save serious damage.

3. The emission of smoke or gas from tank joints, breathers or vents.

Oil Leakage

Another trouble from which transformers occasionally suffer is " weeping," or oil leakage from the tank. It should be realised that an oil leakage does not need a large crack ; only those with welding experience realize how oil apparently

creeps through solid metal, sometimes creeping behind a weld for several inches, and reappearing a long way from the faulty spot. While no reputable manufacturer would dream of shipping a tank which had not undergone the most stringent oil tests, the fact remains that obscure leaks

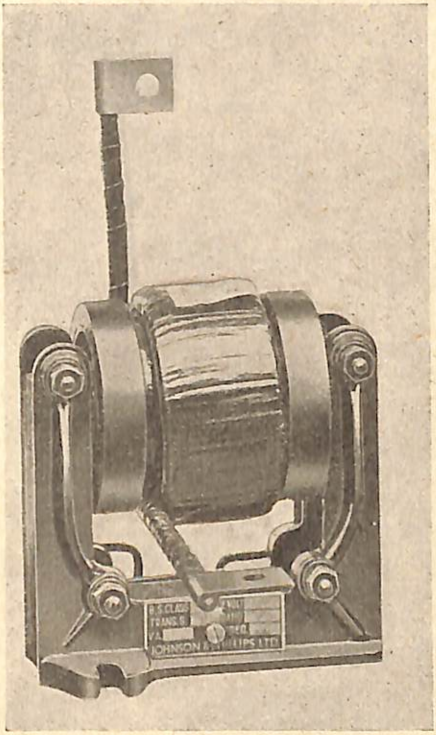

Fig. 23.—Typical wound-primary current transformer

do occur ; occasionally weeks or months after installation. A leak of this sort is naturally a very troublesome thing to locate, and is best found by cleaning the suspected area of the tank with petrol and applying a coat of whitewash,

which will show up the tiniest leak immediately. There are then two courses open :—

1. Drill a tiny hole, say $\frac{1}{8}$ in., into the suspected seam (*not* right through) tap it, and screw in a grease gun nipple. Force in a paste of red lead and gold size, which will harden and stop the leak, if it has been effectively located.

2. Welding. This will, of course, necessitate the emptying of the tank. An interesting method, described by K. Fremlin of Australia (*Electric Journal*, February, 1938), accomplished this on an outdoor transformer, without exposing the core or wetting the oil, although the day was wet. A cylinder of carbon dioxide was connected to the transformer tank, and the oil piped to a clean reservoir at a higher level. The oil was blown out under pressure of the CO_2, which replaced it, thus saving the oil from contact with the damp atmosphere, and filling the tank with an inert gas, which would not form an explosive mixture with oil vapour.

When welding is to be undertaken let it be the best possible ; preferably by the tank manufacturer's staff. Never attempt amateur welding on a tank.

Small Air-cooled Transformers

Maintenance is limited to general inspection of the core coils, etc., as for oil-immersed transformers, and occasional cleaning.

Instrument Transformers

Voltage, or Potential transformers are usually air-insulated up to 3,300 volts, and oil-immersed above this. The general maintenance is as outlined for their larger brothers. It should be noted that the blowing of the primary fuses is not always a sign of a fault on the transformer itself, but may be due to the shorting of the secondary winding. Great care should be taken to prevent this.

Voltage transformers should not be loaded above their rated output (as given on the nameplate) if accurate results

are required, as this tends to introduce errors in both ratio and phase angle.

Current transformers are usually air cooled up to 11,000 volts, and may be either oil or compound filled above this.

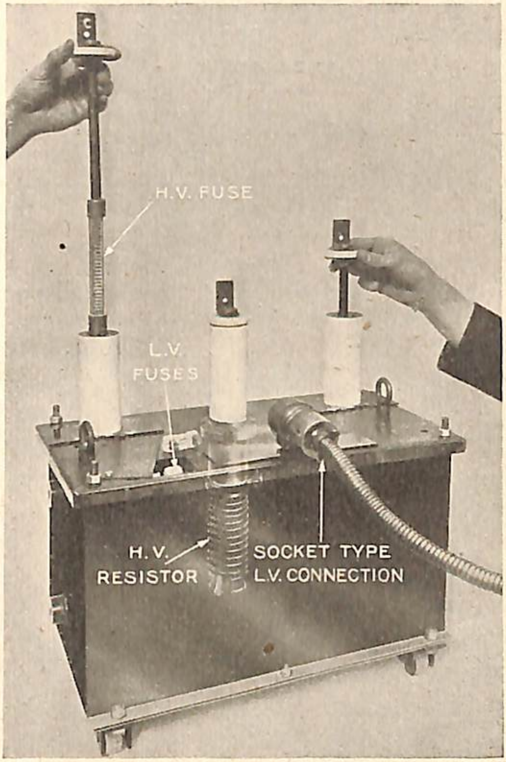

Fig. 24.—Typical voltage transformer with enclosed pattern fuses and current-limiting resistors. (11,000/110 V)

Ratios above 600/5 are usually of the single-turn or bar primary type.

Care must be taken not to open-circuit the secondary circuit, or even to insert high-impedance loads, since this

not only causes a high flux-density in the core, which will cause overheating, but the voltage across the secondary will be very high. If the secondary circuit must be disconnected for any reason, short-circuit the terminals with a piece of wire *before* disconnecting the load. Make sure that the short does not come adrift as you disconnect the circuit, or you will receive a severe shock.

Table giving approximate sizes of wire for different fusing currents.

[*Courtesy of Messrs. London Electric Wire and Smiths Ltd.*]

Fusing Current Amperes	Size of Wire for Different Materials						
	Copper		Tin		Allo-Tin		Lead
	in.	SWG.	in.	SWG.	in.	SWG.	
1	.0020	47	.0076	36	.0084	35	Approximately
2	.0036	43	.0116	31	.0136	29	equivalent
3	.0044	41	.0148	28	.018	26	to
5	.0060	38	.022	24	.024	23	Allo-Tin
10	.0100	33	.036	20	.040	19	
15	.0124	30	.044	—	.048	18	
20	.0156	—	.052	—	.064	16	
30	.020	25	.072	15	.080	14	
50	.028	22	.096	—	.116	11	
60	.032	21	.110	—	.128	10	
80	.040	19	.134	—	—	—	
100	.048	18	.152	—	—	—	

CHAPTER VIII

DOMESTIC AND PORTABLE APPLIANCES

It is probably safe to say that 90 per cent. of troubles experienced with portable apparatus, originate in the flex or plug; and that proper attention paid to these will eliminate breakdowns and waste of time, as well as the risk of serious accident.

In the case of domestic apparatus, the electrician should make every effort to persuade the persons concerned to put matters right, rather than to "patch"; in the case of factory repairs, he himself will have the decision, and should follow the advice he gives to others.

Plugs. Even for domestic use, the three-pin plug should be standard throughout, with switch close to hand, or combined with the socket, and for use where young children may have access, the interlocked variety should be used. Lampholder adaptors are prohibited by I.E.E. Regulations for currents above 1 amp., and are deprecated for use in any situation, even where there is no risk of earth fault. Where such a risk exists, the use of these adaptors is sheer folly, as no arrangements for earthing can be made. For factories and similar situations, the 3-pin plug *must* be used. Where there is risk of dripping water, or for outdoor situations, a watertight type of plug and socket should be used, and for places involving risk of explosion due to inflammable vapours, the flameproof type is necessary.

The commonest cause of trouble in plugs and sockets is overheating, due to the plug being in bad condition, or, as is common, too small for the load which it has to carry. Softening and loss of springiness follow, leading to bad

contact, arcing, pitting, and worse overheating. The only remedy is to clean both plug and socket, and to expand the plug, if of the split type. If very soft, it is best scrapped.

Troubles may occasionally be more obscure. In a cheap type of switch-plug, it was noticed that a black deposit was formed on the plug, and that upon switching off, the arc tended to hang on longer and longer each time, until one day it decided to hang on permanently. Fortunately, the main switch was opened in time to prevent a fire. Investigation showed that wax, used for covering screw heads at the back of the switch, had softened, due to the initial heating, and had run in a fine film over the switch contacts, increasing the overheating. Arcing had volatilized the wax, and caused a fine carbon deposit over the whole of the switch and cover, finally being complete enough to allow sustained arcing round the arc barrier. A thorough cleaning cured the trouble.

Flexibles

A thorough examination of flexible conductors, at frequent intervals, even when apparently in good condition, will well repay the time spent. When faulty places are discovered, it is usually preferable to replace the whole length, unless it is a long piece in which case the faulty portion should be cut out, and the joint well made.

A great deal of cheap rubbish, mostly foreign, is sold at the present time which is useless, and dangerous, it being possible in very bad cases to get a shock off the outside, even when nearly new. Never use anything but good quality flex, preferably CMA grade, even for table lamps. For use where subject to heat, such as for iron cords, special heat-resisting asbestos sheathed cord is preferable.

For situations where a moderate amount of rough handling will occur, " workshop " flex is very good. This is cotton and VIR covered, wormed circular with jute strands, and finished with a braided covering, impregnated with com-

pound. Its chief disadvantage for domestic use is that, when new, it makes black marks on anything it touches, due to the compound on the braiding, but this can be minimised, by wiping and coating with french chalk before putting into service.

Where the flex is to be trailed about on stone floors, exposed to acids and alkalis, run over by trucks, and generally brutalized, cab-tyre cable is unbeatable.

It is no use buying the best possible cable, and relying on twisted joints, covered (?) with a single lap of black tape. Plugs and sockets make the most convenient joints, otherwise solder the joints, lap *well* with tape, warm and paint with anti-sulphuric enamel.

Whatever type of flex is used, examine it at frequent intervals, and if badly abraded, or if it feels brittle, throw it away. Even the small piece that connects the lampholder with the ceiling rose will require replacing every few years. If you don't one day it will break down, burn through, drop the lamp and fitting, and probably start a fire.

When inserting new flexibles into plugs or portable appliances, keep the length of insulation cut back as short as possible, so that the external covering actually enters the hole in the plug or apparatus. Wind tape around to form a bush which is a tight fit in the entry hole.

If the flex has not coloured conductors for identification purposes, do not guess, but ring through or test with a lamp, so that there is no mistake about which core is the earth core. A number of persons are killed every year through this one mistake.

Switches

Designers of switches located on portable apparatus have usually to produce something which is robust and reliable to fit into about half the space to which they should be entitled. Surprisingly enough very little trouble occurs, barring a very occasional breakage of a small part, or

through contact deformation and burning, which are easily dealt with.

Apparatus fitted with Motors

Troubles in apparatus fitted with fractional h.p. motors can usually be divided into motor troubles and mechanical faults.

Motor Troubles

FHP motors suffer, in a minor degree, from the troubles which beset their larger brothers. Possibly the most common are lubrication and commutation troubles.

Lubrication troubles are usually caused by " oilcanitis " on the part of the operator, and troubles are usually due to over-, rather than under-lubrication. FHP motors have usually grease-packed ball bearings, which should require practically no attention whatsoever, or sleeve bearings with an oil-soaked felt pad pressing on the journal. These should require about six *drops* of oil per year. Lubrication instructions are usually given on the machine name-plate, and there is no excuse for disregarding them.

Commutation is usually excellent on modern machines, and providing a daily ration of oil is not given, will remain so for a very long time. When trouble does eventually occur, it is usually found that the brushes have worn completely away, being represented only by large quantities of carbon dust deposited all over the inside of the motor.

Bear in mind that the correct brush grade is just as important to these little pint-size chaps as to large motors and do not, because no spare is at hand, put in a makeshift in the way of a magneto brush or a piece of carbon from a flash-lamp battery. You might, of course, risk this to keep going while a spare brush is obtained, but if you rely on it for a permanency, you may find that, according to the grade of carbon selected, either (a), the brush wears at about

$\frac{1}{2}$ in. per hour, or (b), the brush is doing nicely, but the commutator has definitely seen better days.

OTHER FAULTS may be tested for in the manner described in Chapter I. In addition, the following are also possibilities.

In a single-phase induction motor, with split-phase starting, see that the condenser or reactor for the starting winding is neither broken down nor shorted, and that the centrifugal switch which cuts out the starting winding is operating properly. (If it does not cut in, the motor will not start, and if it does not cut out the starting winding may burn out.) Be very careful with a motor of this type that, if disconnected, it is correctly reconnected, and that the starting and main windings are not interchanged. If this happens it may still start, but will give a very poor load performance, and will overheat badly.

If the machine is repulsion-induction type, see that the short-circuiting device on the commutator is working properly.

Mechanical Troubles

By this is meant troubles external to the motor, which may take any one of several forms, and unless the motor is uncoupled and the machine operated by hand, may give the illusion of a falling-off in motor power. Two frequent ones are binding of machine bearings or gearing, and loose belts. Little need be said on either score, except that loose belts are sometimes very tricky to locate, as the belt may seem perfectly O.K. on light load, but slip badly on a heavier one. Rubber belts which have perished can cause a good deal of trouble in this direction, and many a revolving brush on a vacuum cleaner has gone for re-bristling long before its time, owing to wrong diagnosis of falling efficiency.

Apparatus with Heating Elements

Under this heading come radiators, cookers, kettles,

laundry irons, etc. Trouble may occur in the switches or internal wiring, or in the heating elements themselves, the latter being the more usual.

Very little actual instructions can be laid down, on account of the diversity of designs in different manufacturer's apparatus. It is, however, worth bearing in mind that :—

1. With domestic apparatus, never be " bounced " into repairing anything which is the property of the Supply Co. on H.P. agreement, with free maintenance. The hirers can do it far more efficiently and quickly than you can, and if a repair has been attempted, may repudiate responsibility.

2. When a manufacturer's spare is obtainable, it is not worth while to spend a lot of trouble on a home made element. Some types are, of course, hopeless to attempt. Elements of the type enclosed in a metal sheath packed with magnesium oxide, are not repairable, although it is only fair to say that they very seldom give trouble. The same applies to the immersed type of water-heating element.

Elements consisting of wire spirals on mica and fireclay supports, can be repaired, but it is preferable to obtain complete spare elements. If it is decided to rewind the existing supports, take care that the wire selected is identical with the original winding, both in size and material, and that in the case of spirals, the diameter of the spiral is the same, and does not jam in the fireclay grooves when hot. Take care not to nick or scrape the wire, thus forming local hot spots, which will burn out quite soon. Also watch your joints at the terminals. A plain pinch joint, using three washers and a nut and bolt is the only type which will serve. Soldering is, of course, useless, and the oxide film will soon put paid to a twisted joint.

Do not screw down fireclay elements too tightly, or they will crack when heated. In the case of plug-in elements, do not forget to clean the plugs, and replace if softened by heating.

When dealing with bare connections, see that there is

plenty of clearance between connections and metal cases, and that there is no risk of connections bending and shorting to the case. Examine and clean all insulating surfaces, and scrape off any burns or splashes of metal. In radiators, the heat frequently sets up air currents which deposit dust all over the interior. See that this does not form leakage paths from live parts to earth.

Examine the earthing connection, and make sure that it is efficient, and not disconnected or corroded.

Bells

Faults on bell or buzzer systems can be detected by a process of elimination. First examine the battery, and having ascertained that this is in good condition, disconnect it, and connect it directly to the bell. If this does not ring, make sure that there is a circuit through the coils, and that the contacts are in order. Clean and adjust them, as they may have slacked back or screwed up tight under vibration.

If both bell and battery are in good condition the fault must lie in the wiring or push. Pushes, especially if installed in exposed positions are not above suspicion. Re-connect the battery and bell, disconnect the wires from the push, and touch them together. If the bell still does not ring, the fault is in the wiring. As wires do not break without good cause, examine the route taken by the wiring for mechanical damage. In old houses, wiring was frequently installed in the most peculiar manner, frequently emerging over built-in shelving where it was liable to have boxes laid on it. It also ran through the cracks of doors, where the door finally put paid to it. It was also frequently nibbled through by mice.

If there is more than one push, and all fail to ring the bell, then assuming bell and battery to be correct the fault must lie in the indicator or in a common wire.

When the trouble has been discovered, take steps to prevent its recurrence, by varying the route to a more sheltered location.

CHAPTER IX

INSULATING MATERIALS USED IN REPAIR WORK

THERE are literally thousands of insulating materials, each supreme in one particular application, and the subject of insulation, thoroughly treated, would fill, not a book, but a whole library. Every material has its good points and its bad ones. One is mechanically strong but not flexible, another is both strong and flexible, but absorbs moisture, a third has none of these disadvantages, but will not stand high temperatures, one would be very good indeed, but dissolves in hot oil, and so on. Let us, therefore, confine ourselves to the more common varieties, which we are likely to require for repair work, classifying them according to their application.

Tapes

COTTON and SILK tapes are used for insulation of armature and field coils, and similar applications, the silk being reserved for use where space-saving is more important than first cost. They are, however, very hygroscopic, and useless unless varnished or impregnated. LINEN or CAMBRIC tapes come into the same category. A coarse variety of cotton tape, known as BOOT WEBBING is frequently used on the outside of coils, to resist abrasion.

EMPIRE TAPE is a cambric or (where space is precious), silk tape, coated with a flexible nsulating varnish, either yellow or black in colour. It is also used for coil taping and general insulation, and is practically non-hygroscopic. It does, however, gradually deteriorate on exposure to air, and

should be protected by painting. If used for small articles, or where it is required to turn sharp corners, such as on former-wound coils, " bias cut " tape should be used. This is cut so that the fibres lie diagonally across the tape, and it will deform without buckling or tearing.

Black tape (or " sticky " tape) is cotton or linen impregnated with an insulating compound, and is probably the best known and most widely used insulating medium existing, being used in many jobs which have nothing to do with electricity, from splicing cricket bats to mending bicycles. It is mechanically strong, convenient in application and resists abrasion wonderfully well, but should be used with a little discrimination. It is, for example, useless in the presence of oil, and deteriorates gradually in air, becoming hard and dry. It is non-heat-resistant, and has a corrosive effect on untinned copper.

The best method of applying it for a permanent job is to apply it over a layer of Empire or pure rubber tape, if the voltage is high, or the copper is untinned. Wind it *tightly*, warm with a blowlamp and squeeze tightly with a cloth like making a plumber's wiped joint. Paint with anti-sulphuric enamel, and you will have a joint which will last an amazing length of time as compared with a plain wrapping, and will look as workmanlike as a good wipe joint in a lead pipe.

Other tapes, such as cotton impregnated, and pure rubber, are produced specially for cable jointing, and are beyond the scope of this book.

Asbestos tape is also made, and is useful for service where heat-resisting powers are required. It is, however, weak mechanically, and extremely hygroscopic. Mica tape, made with mica on a backing of strong paper, silk or cotton is used for high-voltage machine windings.

Glass tape, once considered an empty dream, is now commercially obtainable. (It is also available as a covering for insulated wire, and resembles the finest silk.) Its outstanding feature is that it will stand very high temperatures,

and is mechanically strong. It has the disadvantage of being hygroscopic, by capillary attraction between the fine fibres.

Tubing or Sleeving

Tubing is used for slipping over single wires, such as coil ends, etc. The tubing resembles Empire tape in appearance, and is, in fact practically identical in composition.

For small low-voltage wires, cellulose acetate sleeving is made, in a range of bright colours.

Sheets, Boards, and Tubes

Paper and pulp products include many varieties of press-board, made in boards and sheets of varying thickness. They are tough, dense, strong, and when impregnated to avoid moisture absorbtion, make extremely good dielectrics, and have a variety of uses, from the lining of oil circuit breaker tanks, to the lining of machine slots, and coil spools of all descriptions. Most of these materials are sold ready impregnated with varnish, or oil; if a choice is available between plain and impregnated, always choose the latter, as on account of the dense structure of these materials, impregnation is not easy.

Fibre board, once largely used, has largely been displaced by moulded plastics, as it has a great capacity for absorbing moisture, which not only causes a considerable reduction in dielectric strength, but tends to swell and warp as well. (Many will remember the fibre bush in the contact-breaker of the old-time magnetos, which swelled whenever it rained, and caused sticking of the arm.)

Fibre has, however, two good points, it is immensely tough and strong, and comparatively cheap, so that it is a most valuable material where high-grade insulation is not required, and is largely used for slot wedges on machines. In thick boards it will be found very useful for making up spacers, and various gadgets, which can be sawn from the board. Grey fibre is the best variety for this.

Asbestos

Ordinary asbestos board, made from flaked asbestos and a bonding cement, is used for arc chutes, air-break switch linings, etc., where a material which resists arcing is necessary. Boards are usually a mottled grey in appearance. They can be sawn with a hacksaw, or drilled, but are brittle and easily broken, being therefore unsuitable for situations where high mechanical strength is required. The insulation resistance is uncertain, varying greatly with the amount of moisture absorbed.

Other asbestos products include boards impregnated with asphalt, etc., giving a black product of high mechanical strength, and good insulating properties, largely used in place of slate for switchboard panels, and also for lever switch crossbars, and similar applications, but which is not arc-resistant.

Mica

Mica like asbestos, is an inorganic substance, and is also heat-resisting. Unlike asbestos, it is non-hygroscopic, and has an extremely high dielectric strength. It is usually met with in the form of micanite, which consists of mica splittings formed into a solid material with a bonding agent. Upon the properties of the bond depend the properties of the micanite, and some varieties will stand much higher temperatures than others. Mica is used for slot linings on high voltage machines, when it is usually moulded to the shape of the slot. It is also used for the supports of heating elements. and for the dielectrics of condensers. Its greatest use is, however, for the insulation of commutators, both as pure mica and as micanite in the form of intersegmental pieces, and for the moulded end rings. When required for commutator repairs, it should always be ordered as "commutator mica." Mica tape is also made with a backing of strong paper.

Wood

The ordinary common soft woods are useless for insulation purposes. Certain of the choicer woods, such as maple, spruce, and best of all teak, are suitable, but always require drying and impregnation treatment, with paraffin wax and linseed oil, or varnish if any real reliance is to be placed on their insulating properties.

Moulded Compounds

Under this heading a very large number of materials can be grouped, and new materials are being added almost every day. Many of them are however, expressly developed for moulding processes, and are not, therefore, of interest to the repair man, who wants something which can be purchased in a usable form.

Ebonite, a vulcanised rubber product, at one time widely used, is rapidly falling into disuse. It tends to be brittle, and mechanically weak, is subject to deterioration due to the action of sunlight, the atmosphere, and, of course, oil. It has largely been superseded by synthetic resin or bakelite products.

Bakelite Products

There are many varieties of these materials, all of which consist of a "filler," or "body" impregnated with a synthetic resin, and solidified under pressure and heat. Many are made up as moulding powders, with a filler of wood or asbestos ground to a fine flour, but for solid sheet materials such as a repair man would use, they can be boiled down to three: paper cloth or canvas and wood.

Bakelised Paper is made of sheets of high-quality paper, treated with bakelite varnish, and compacted under heat and pressure into boards of varying thickness or rolled upon mandrels to form tubes of various diameters. Both sheets and tubes have a glossy finish, great mechanical strength, and can be machined. It is, however, important

to note that after cutting, drilling, or any operation which exposes the edges of the laminations, the raw edges must be varnished, or moisture will be absorbed.

Bakelised Fabric is another material which is generally similar, but is made with laminations of cotton duck, or canvas, instead of paper. It is more expensive than paper, but more suitable where small parts of great mechanical strength are concerned.

Bakelised Wood must not be confused with bakelite having a ground wood filler. The wood in this case is solid plywood, impregnated with varnish, and heat-treated. In appearance the material resembles wood with a first-class French polish finish. It is very expensive, but largely used where conditions are exceptionally severe, such as for oil circuit breaker tension rods.

Varnishes and Paints

The number of insulating varnishes is so great that little but a brief outline can be given of a few varieties.

Varnishes can be roughly divided into two classes: air-drying, and baking. The latter class, usually compounded with an oil base, are more flexible than the air-drying types. This is of importance where large variations of temperature cause expansion and contraction of the insulation, as if the varnish has little flexibility, it will tend to form minute hair-cracks, which will hold dirt and moisture, and may, in time cause peeling-off. It is, however, useless to try to use baking varnish, unless facilities are available for baking at a temperature of say 100° C. for several hours, in a stream of air.

Whatever type of varnish is selected, it *must* be used at the temperature and consistency recommended by the manufacturers, and must not be too thick or too thin.

For some types of apparatus, impregnation is the only method which will give satisfactory results. By this is meant the actual soaking-up of the varnish to fill the spaces between

the fibres and to exclude moisture. The ideal treatment is to dry in a vacuum oven so that the moisture is driven off at a comparatively low temperature, and then to flood the oven with varnish under pressure, so that it permeates the coil very thoroughly. As this is not always possible, the next best thing is to dry in a stream of air, dip in varnish and bake.

Where impregnation is not possible, as for instance in the case of closed-slot coils wound on the machine, the only alternative is to use an air-drying varnish applied by brushing or spraying.

It would be possible to discuss for hours the relative advantages of shellac, copal, asphalt, and resinous bases; linseed *v.* tung oil . . . etc.; but the practical man has no time to devote to becoming a varnish technician in order to choose a can of varnish. The commonsense way to choose a varnish, like any other material, is to select any of the many reliable manufacturers, and tell him the purpose for which it is required. It is to his advantage to sell you the most suitable type, and he will also give the fullest directions as to its use. Never buy varnish blindly, or you may find yourself using a very special and costly varnish on odds-and-ends, and don't be tempted to use ordinary carriage varnish on jobs where insulation is important.

Paints

The most suitable general-purpose paint for the repair man is anti-sulphuric enamel, which is obtainable in a number of bright colours as well as black. It is quick-drying, non-corrosive, and does not deteriorate or flake off. It is also non-conducting although it should not be relied upon for insulation, to any extent. In this respect it differs from other black paints, many of which are made with a carbon base which is, of course, definitely conducting.

Ordinary paints should be used with the greatest care, a lead-base paint, for example, must never be used under

oil. Repairs to switch and transformer tanks must always be carried out with a special oilproof paint.

Compounds

These may be divided into three classes ; sealing, impregnating, and filling.

SEALING compounds are usually sold in stick form, and are often used for sticking down the end of the taping on a coil, together with many other uses which will suggest themselves. Applied by melting with a hot iron, like a blob of solder, it is almost as good a friend as the proverbial black tape.

IMPREGNATING compounds are used like varnish, by dipping, or immersion under pressure. As the compound solidifies on cooling there is no question of baking after impregnation.

FILLING compounds are used for excluding air and moisture, and providing an insulating barrier between live conductors in all kinds of apparatus, such as cable boxes, small transformers, and the busbars of metalclad switchgear, etc. They vary considerably in composition, melting point and price, but nearly all have a bituminous base. Once again, it is impossible to recommend any particular type, as in the case of cable boxes, switchgear, etc., the grade of compound is almost invariably specified, if not actually supplied, by the manufacturer of the gear. When in doubt, approach the manufacturer, giving particulars of working temperature, dielectric strength required, and (this is important) risk of contamination by oil. Oil-proof compounds are obtainable, but ordinary compound is dissolved by oil.

When compounding. the article should be pre-heated if possible, and, after the compound has cooled slightly, topping-up is required to fill the space left by contraction. Do not, however, forget to allow space for the compound to expand ; a container completely filled may burst when the

temperature rises. A melting point of 55° - 65° C. is usually satisfactory, except for very hot situations.

Plastic compound can be obtained, which can be regarded as insulating putty, and can be moulded round as object at ordinary temperatures. It is exceedingly useful where, say, a bolted joint in a busbar requires taping. By puttying the joint to a smooth external finish which will take a uniform wrapping of tape, not only is a neat joint obtained, an impossibility by straight taping, but air pockets inside the taping are eliminated, which may matter a great deal on high voltages, where risk of corona is present.

Cements

Two varieties of cements will be found particularly useful.

1. Oil-tight jointing cement, as used for cementing in paper insulators to the top plates of oil circuit breakers. It consists of a mixture of one part of glycerine to about four parts of litharge. It should be well mixed, used immediately, and will set in about 2 hours, and can be loaded in about 24 hours.

2. A cement for compound leaks can be made from sodium silicate (water-glass) and carborundum powder. Mix to a thick paste, plug up the leaks, and allow to harden.

Soldering. To tell you how to solder would probably be an impertinence, so let us confine ourselves to a discussion on fluxes. Don't use killed spirits, or any other acid flux on electrical work, as it causes corrosion. For fine wires, as in low-volt coils, etc., the best flux is powdered resin, made into a paste with *pure* methylated spirits or turpentine.

CHAPTER X

TEMPORARY REPAIRS AND SALVAGE

The ability to make ingenious temporary repairs is a very valuable gift, and may frequently save a great deal of money by preventing a long shut-down at an inconvenient time. Too much stress cannot be laid however, upon the folly of relying upon the " lash-up " type of repair for permanent service. A man who does so will find one day that the majority of his plant is a mass of temporary repairs, all of which are due to give trouble sooner or later, and, if his luck should be out, all at once. It is one thing to replace a faulty run of wiring to a motor, by V.I.R. cables slung from roof girders by loops of tape for half a day, while the fault is being repaired, but it is quite another to allow the temporary wiring to function for weeks or even months, until trouble arises with representatives of the Supply Company, Insurance Company, or the Home Office, or, worse still, a fatal accident or a fire results.

Motor starters sometimes will not hold on owing to trouble with the low-volt coil. What happens? A piece of string or a loop of wire is used to retain the handle, which it does, just as well as the coil, *except* that the motor now has no overload or low-voltage protection.

Bear in mind, then, if you are one of those ingenious people who, like Kipling's artificer, " given a screwdriver and a drum of oil, could teach a stolen bicycle to do type-writing," that you should not allow ingenuity to outrun discretion, nor sacrifice safety to expediency.

Salvage

In this case, the word " salvage " is intended to refer to the

rapid getting under way again when a considerable quantity of plant has been shut down by a major calamity, such as fire or floods. Possibly no other situation offers so much scope for ingenuity, for here detailed instructions are not possible, and you will have to use your own initiative in no small degree. Assume, for instance that you are faced with such a situation. A number of motors, and their control gear are involved, and you start from scratch, with a first class mess. It is no use throwing up your hands, and cursing, neither is it any use rushing round working like a beaver at odd bits here and there—you must first take stock of the situation, and work out a plan of campaign, according to the damage.

Your first worry is your supply. If all your cables have gone, you will have to run temporary ones, with some sort of switchgear to control them. If you have a large high-voltage installation, your best move is to get in touch with the manufacturer, to see if you can arrange for the loan of a few temporary equipments while repairs are being carried out to your existing gear, unless the damage is slight enough to be put right in a few hours. If a low-voltage installation, a few ironclad switch-fuses mounted on a wooden framework will probably fill the bill. Remember always that safety must come first. It may save time and trouble to have a lot of live metal exposed, but if an accident occurs, you have a very good chance of being prosecuted for manslaughter.

Having decided upon the methods to be adopted to restore supply, look over your machines, and determine what steps will be necessary to restore them to working order. If fire has been the trouble, machines which have been in the centre of a fierce blaze will probably be complete " write-offs." If they have escaped the worst of it, they may have their insulation charred, and will need complete re-winding before they are fit for anything, or they may be covered with the grime, smuts and water that are inseparable from a fire,

and may be serviceable after a minor overhaul and clean-up. The same may apply to their associated control gear.

Flood is much more uniform in its effects. Anything which has been submerged (unless of the watertight type), will be unserviceable, but nothing need be completely ruined, if care and intelligence are shown in its overhaul.

The effects of submersion upon a machine are roughly as follows :—

1. All insulation and windings will be completely saturated, with an insulation resistance of practically zero.

2. Oil will float out of the bearings, and be replaced by wet grit.

3. As the flood subsides, or is pumped out, floating oil and dirt will form a film all over the machines and all apparatus which has been submerged.

Your object will be, then to clean and dry everything as soon as possible, and upon the manner in which this is done depends the whole of the subsequent life of the machine.

Firstly as to cleaning. Since the machine has been completely submerged, a little more water will not hurt it, so do not be afraid of using water to remove the oily deposit. Use a high-pressure hose, if you have one. (Remove the rotor from machines.) Having washed off as much oil as possible drain off all free water, and wipe as dry as possible, using a solvent such as petrol or carbon tetrachloride to remove the remaining oil, if necessary. Make sure the ventilation is good, on account of the fumes in both cases. Do not use benzole, and go carefully with the other two, if they show signs of attacking the varnish. Paint the shaft journals, when dried, with a rust-preventing composition (if you have none, smear with red lead and oil). With d.c. machines do not forget that water may actually be present inside the commutator, but if you decide to loosen the end ring, to let it out, clamp the segments firmly with a binding of wire, or you will add a commutator rebuild to your programme.

Drying

The only satisfactory way of drying a machine that has been really saturated, is by means of an oven. The method of applying a low current to the windings, as used for machines which are merely moist, is usually too risky, although in the case of small low-voltage squirrel cage motors, it might be successful. An insulation test may show encouraging readings, but do not forget that insulation resistance falls with a rise in temperature, so that a reading which seems satisfactory at normal temperature may drop

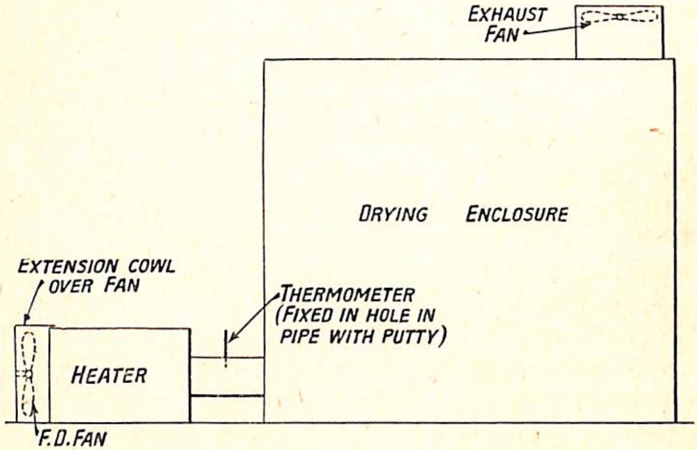

Fig. 25.—Diagrammatic arrangement of drying oven and heaters

sufficiently to break down when hot. Far better to rely on oven drying, and play for safety.

A drying oven of a size to suit the number of machines to be handled is not a difficult thing to rig up. All that is required is an enclosure with an inlet and outlet, and some means of supplying hot air. It can be rigged up of almost anything, steel sheets, asbestos wallboard, plywood, bricks, or even a wooden framework covered with thick cardboard,

all joints being sealed with gummed strip. A fan and heater are the next requisites, to maintain a fair flow of air through the oven. The heater is placed close to the oven, and connected to it through suitable trunking (an old stove pipe or the like), and the fan, if of the "pusher" type, is placed behind the heater. If the fan is of the exhaust type it is placed in the "chimney" of the oven (fig. 25).

The heater can be anything which will heat up the amount of air that the fan can deal with up to 100° C., or thereabouts. If electric resistance elements are available, an old oil drum can be arranged with the elements inside. If you have not got your supply on again, and electric heaters are not available, use the old oil drum anyway, and heat it from the *outside*, by gas jets, blowlamps, or a coke brazier. These methods are not nearly so easily regulated, however, and care must be taken that the air supply is not made too hot. A thermometer should be placed in the supply pipe near the oven, and another stuck through the wall of the oven in the centre of one side.

The air temperature should not be allowed to rise too rapidly. It should be kept low at first, and brought up to say 80°C., in a matter of 4-5 hours. It can then be allowed to rise to an absolute maximum of 120° C. (on the thermometer nearest the heater), providing that the machine windings themselves do not get hotter than about 80° C., as measured by the resistance method (see page 69).

It will readily be understood that if the temperature is allowed to get too high, or is raised too suddenly, there is a danger of steam forming in the saturated coils, which might actually cause them to burst.

After a period of heating, varying from a few hours for a small machine to several days for a large one, the windings should be dry. It will considerably assist matters if leads are brought out from each winding, suitably labelled, to a point outside the oven, so that temperature and insulation resistance measurements may be made without shutting

down the drying process. The leads should be meggered before commencing operations, to make sure that false readings do not occur through faulty leads. If it is not convenient to bring out leads from all windings, it would be a great help to bring out leads for two temperature measurements, and two insulation resistance measurements, which will form " samples " for the whole of the oven. One of the temperature measurements should be on the smallest machine, as its temperature will rise more rapidly than a large mass, and give a quicker indication of what is happening in the oven.

When the insulation resistance is considered satisfactory, the machine may be removed, reassembled and run on reduced voltage for a time, except in the case of machines up to say 440 volts, which can be put back on full voltage for a few hours, after which the insulation resistance should be again checked and the machine can be put back on load.

Opinions differ as to what insulation resistance is satisfactory, but a rough rule is that 1 megohm is sufficient for 440 volt machines (or slightly less in the case of very small motors). This figure is, of course, for normal temperature (16° C.) and the I.R. will drop to about $\frac{1}{3}$ of this for a temperature of about 80° C., so that if it shows about 300,000 ohms, at 80°, it can be put in circuit. For machines above 3,000 v. the insulation resistance must be at least 1 megohm per 1,000 v. for moderate capacity machines.

Flooded switch and control gear and transformers may need similar treatment, depending upon the voltage, and the type of gear. Remember that anything which is immersed in oil, unless hermetically sealed, will be affected by water, which will displace the oil, so do not be surprised, if you open up a circuit breaker or transformer, to find the tank full of water, and the oil missing.

Instruments and meters will probably require the attention of the manufacturer, as even if the coils are dried, pivots are certain to be rusty. The same remarks apply to relays.

In drying switch and control gear, a sharp lookout should be kept on any fibrous insulation, such as wood or fibre, which may give trouble by warping badly in drying. This remark applies particularly to gear up to 440 volts, where such insulation is chiefly used. If the warping is going to affect the mechanical operation of the gear, it is as well to be forewarned, so that spares can be obtained or new parts made while drying of the machines is going on, and the discovery is not made when everything else is ready to go back on the line.

If gaskets have been damaged, it is useful to remember that a temporary oil-tight joint can be made on say, a cover plate, by the use of a piece of soft lead wire, about 1-16th in. in diameter, run round the joint *inside* the bolt circle, with the two ends crossed, if the cover is pulled down fairly tight. It can never be left as a permanent job, however, as the lead "flows" and gradually flattens, leaving the joint slack. If tightened occasionally, it will hold up until new gasket material can be obtained.

Recommended Brush Grades. (Morganite and Battersea Carbon).
(Courtesy of the Morgan Crucible Company).
Note.—Brush pressure 2 lb./sq. inch, except where otherwise stated. It is assumed that mica is undercut except where specifically mentioned.

QUALITY	Contact drop at normal Current Density Volt.	Approx. Maximum Commutator Speed Ft. per Min.	Normal Current Density Amps. per sq. in.		SPHERE OF USE AND CHARACTERISTICS
			Comr.	Rings	
Link One ..	.95	10,000	60	—	Stationary machines running under good mechanical conditions. Very silent.
Link IM3 ..	1.8	6,000	40	—	Industrial A.C. commutator motors, also used as an advanced commutating brush for difficult D.C. machines 3 lb./sq. inch.
Link HM3 ..	.90	10,000	65	75	Rotary Converters.
Link HM5 ..	.90	10,000	65	75	Turbo-Exciters and large D.C. machines.
Link HM6 ..	.85	10,000	65	75	D.C. machines, large and small, and on Turbo-Alternator slip rings.

QUALITY	Contact drop at normal Current Density Volt.	Approx. Maximum Commutator Speed Ft. per Min.	Normal Current Density Amps. per sq. in.		SPHERE OF USE AND CHARACTERISTICS
			Comr.	Rings	
Link CM2 ..	.25	5,000	100	150	Slip rings and D.C. machines up to 10 volts. Pressure for slip rings $2\frac{1}{2}$ lb./sq. inch.
Link CM3H	.35	6,000	80	100	Similar to CM2, but more graphitic. Used for Rotary Converter slip rings, low voltage Dynamos and Automobile Starter Motors. Pressure for slip rings 3 lb./sq. inch, Starter Motors 8 lb./ sq. inch.
Link CM5H	.50	6,000	75	90	Similar to CM3H, but more graphitic, for Rotary Converter slip rings, also for Induction Motor slip rings and Automobile Machines. Pressure for slip rings 3 lb./sq. inch.
Link CM6 ..	.45	5,000	70	90	D.C. machines up to about 50 volts.
Link Ao ..	1.0	4,000	45	—	D.C. machines.
Link B6 ..	1.0	4,000	50	65	Hard graphitic brush of close texture for machines of all voltages.
Link C4 ..	1.1	3,000	40	—	Hard, dense brush for machines having high reactance volts or rather hard mica. Very widely used for 500 volt ordinary Industrial Motors; also used for Switch Contacts.
Link EG0 ..	.95	5,000	65	75	Comparatively soft brush used on heavy current machines of low voltage, or automobile generators and to a limited extent on slip rings.
Link EG3 ..	1.0	5,000	55	65	Considerably harder than Link EG0. Widely used on Traction Motors with recessed mica and on other D.C. machines ;also on A.C. Commutator Motors. Very suitable for contacts subjected to violent sparking and severe mechanical shocks.
Link EG4 ..	.90	4,000	55	—	Possesses similar properties to EG3, but is suitable for machines with flush mica.

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